THE MAGAZINE THAT FEEDS MINDS

HOW IT WORKS

SCIENCE ENVIRONMENT TECHNOLOGY TRANSPORT STOR SPACE

INSIDE

NATURE'S GIANTS

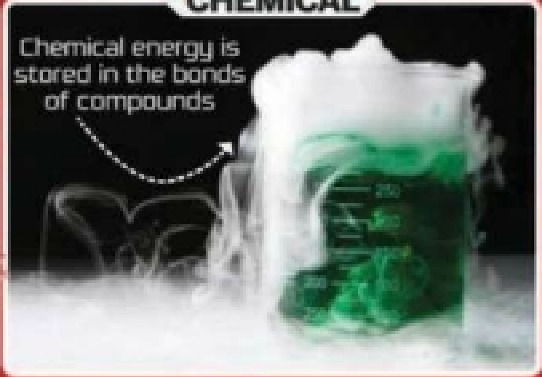
THE CREATURES THAT USE THEIR SIZE TO SURVIVE

BATTLESHIPS

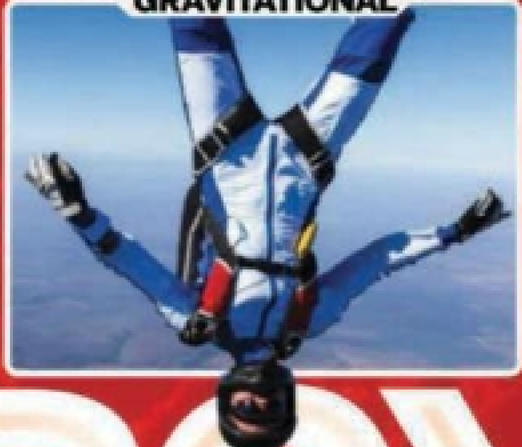
Warships with the advanced firepower to rule the seas

ELASTIC

KINETIC


CHEMICAL

Chemical energy is stored in the bonds of compounds


GRAVITATIONAL

HEAT

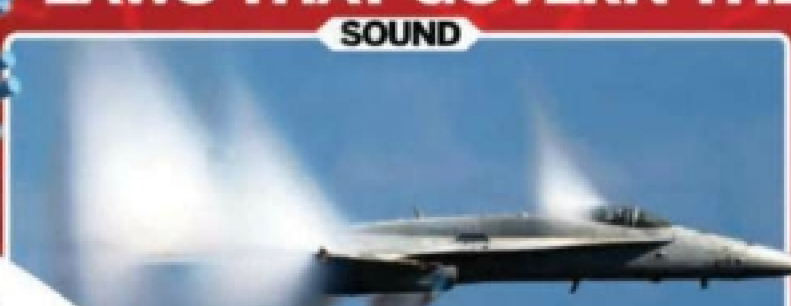
Whenever something heats up or cools down it uses energy

MAGNETIC

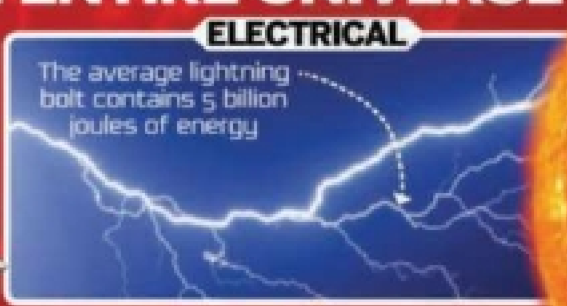
ENERGY EXPLAINED

LIGHT

EVERYTHING YOU NEED TO KNOW ABOUT THE LAWS THAT GOVERN THE ENTIRE UNIVERSE


SOUND

A sonic boom generates an explosion of sound energy


ELECTRICAL

The average lightning bolt contains 5 billion joules of energy

NUCLEAR

173,000 terawatts of solar energy strikes Earth continuously

BACTERIA

There's more to these organisms than just food poisoning...

MISSION TO JUPITER

THE 8-YEAR JOURNEY TO THE JOVIAN SYSTEM EXPLAINED

+LEARN ABOUT

- FJORDS
- PAYLOADS
- NEXUS 7
- SALMON
- TYRES
- TRITON
- HORNETS
- MICROFILMS
- CARBON DATING
- BIONIC HUMANS
- TRACHEOTOMIES
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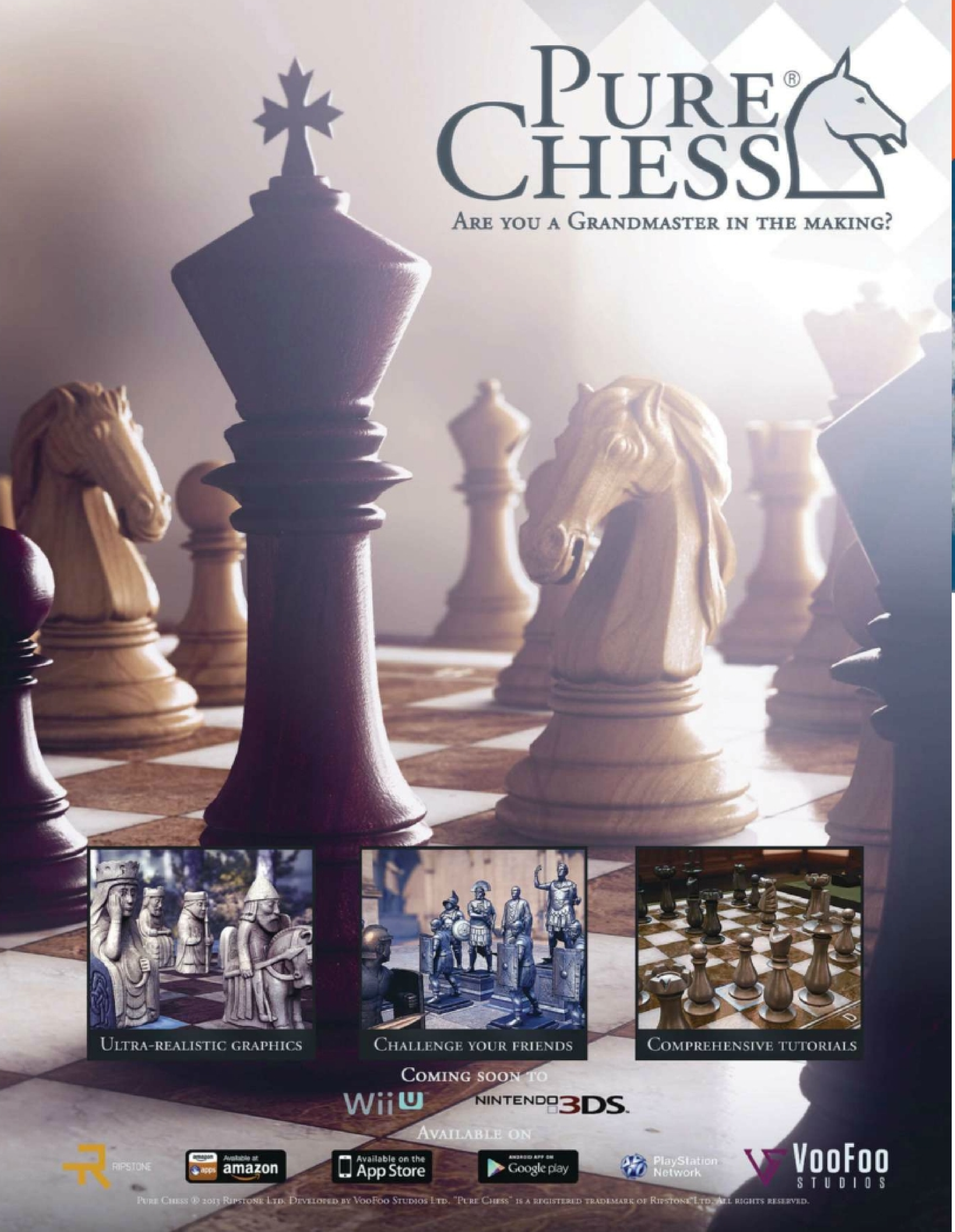

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ISSUE 51

WELCOME

The magazine that feeds minds!

Page 68
The Shuttle's payload bay is an awesome sight out in space

Energy is defined as the ability to do work, but what does that really mean? We know energy is a really useful thing: it turns food into fuel for our bodies, it turns sunlight into power for plant growth, it releases arrows from bows, moves the compass needle when you're lost and so much more. So this issue, we've got down all the essential energy basics you need to better understand life, the universe… and, well, everything! Once you've grasped a few simple rules you may see physics in a whole new light.

We also take a look at the planet's biggest terrestrial animals and ask just how they have adapted to survive despite – or because of – their immense size. These behemoths of the natural world are quite remarkable in their specialisations and abilities, and we're sure you'll thoroughly enjoy reading about their supersized biology.

Enjoy the issue.

Helen

Helen Porter
Editor

Meet the team…

Robert
Features Editor
I had a hairy time this month ducking the Ankylosaurus's deadly tail. Luckily I got the information I needed for an article on the dino.

Jackie
Research Editor
I've really enjoyed the bionics feature – the advancements being made in that field are amazing. Check it out on page 52!

Marcus
Designer
I've had a wonderful time learning more about the JUICE project, which is tasked with exploring Jupiter and its incredible moons.

Adam
Senior Sub Editor
A sockeye salmon doesn't have it easy, but nobody can accuse it of leading a dull life, as you'll discover in our fishy Environment feature.

What's in store…

The huge amount of information in each issue of How It Works is organised into these key sections:

Science
Uncover the world's most amazing physics, chemistry and biology

Technology
Discover the inner workings of cool gadgets and engineering marvels

Transport
Everything from the fastest cars to the most advanced aircraft

Space
Learn about all things cosmic in the section that's truly out of this world

Environment
Explore the amazing natural wonders to be found on planet Earth

History
Step back in time and find out how things used to work in the past

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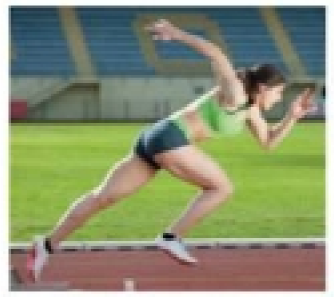

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Meet the experts…

Rik Sargent
Going supernova
This issue Rik from the Institute of Physics reveals what happens at the end of a massive star's life, stage by stage, resulting in the biggest explosion in the universe, before taking some of your questions in the Brain dump.

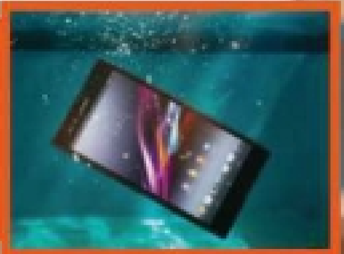
Ella Carter
Fjords
Ella is a marine biology and oceanography expert, with a degree in the subject, and this issue she reveals the spectacular fjord formation process as well as the wildlife that calls it home.

Luis Villazon
Nature's giants
From elephants to giraffes and big cats, **How It Works** regular and zoology specialist Luis gets to the heart of the biology of the planet's largest animals, explaining how they survive.

Alexandra Cheung
Energy
Our cover feature this issue comes courtesy of science explainer Alex who brings the laws of energy into focus, explaining why it cannot be created nor destroyed.

Laura Mears
Bionic humans
Biology guru Laura is taking a close-up look at the fascinating world of biomechanical engineering revealing how prosthetics and artificial organs are currently on the verge of something big.

How do you make a smartphone water-resistant? Find out now on page 61



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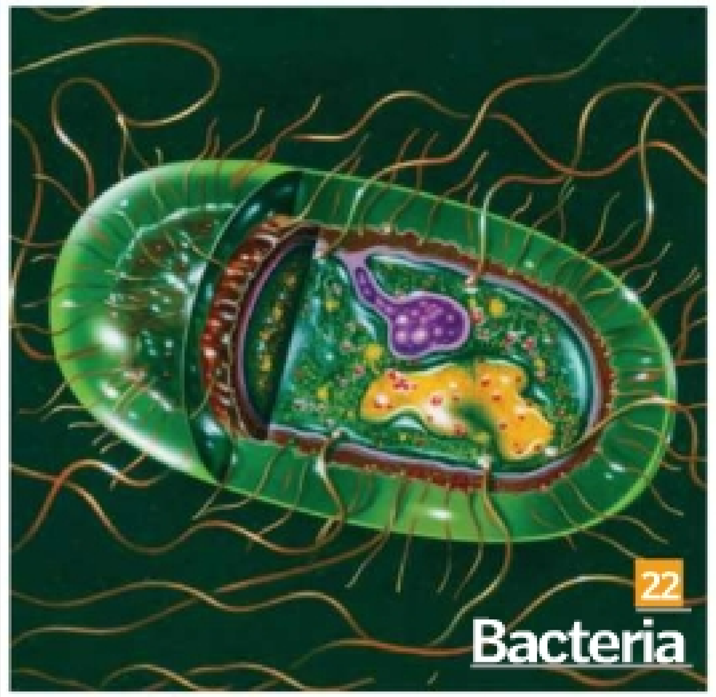

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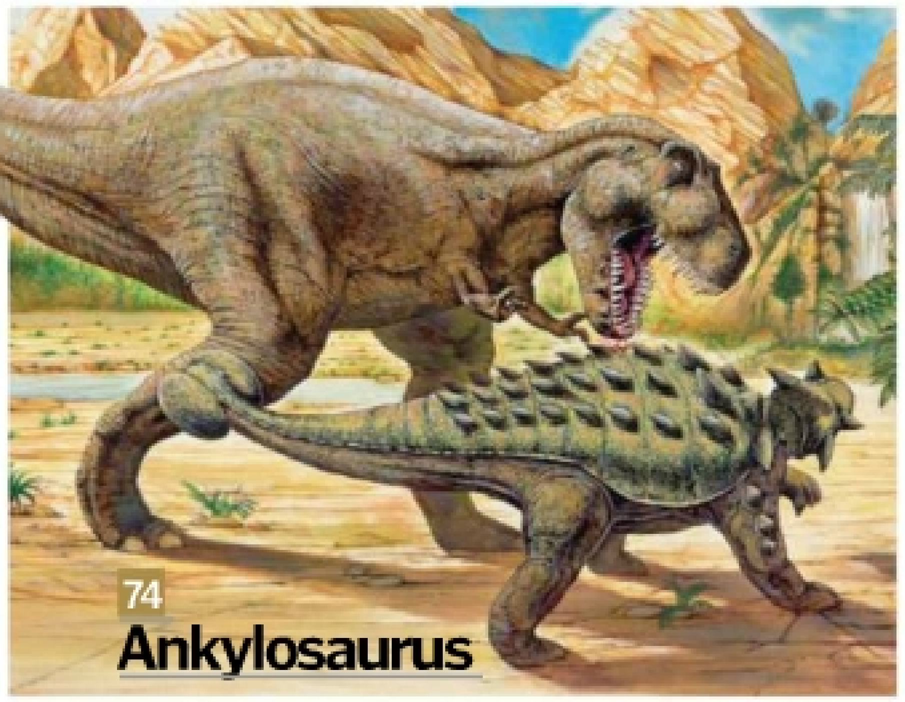

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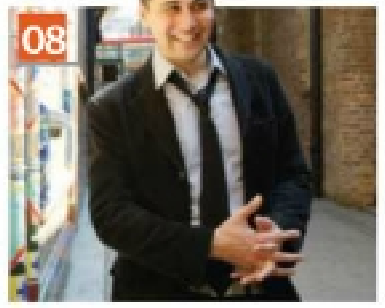

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The place where we answer all your most curious questions

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…hit a hole-in-one and plaster up a hole in the wall to perfection

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Our readers have their say on all things science and tech

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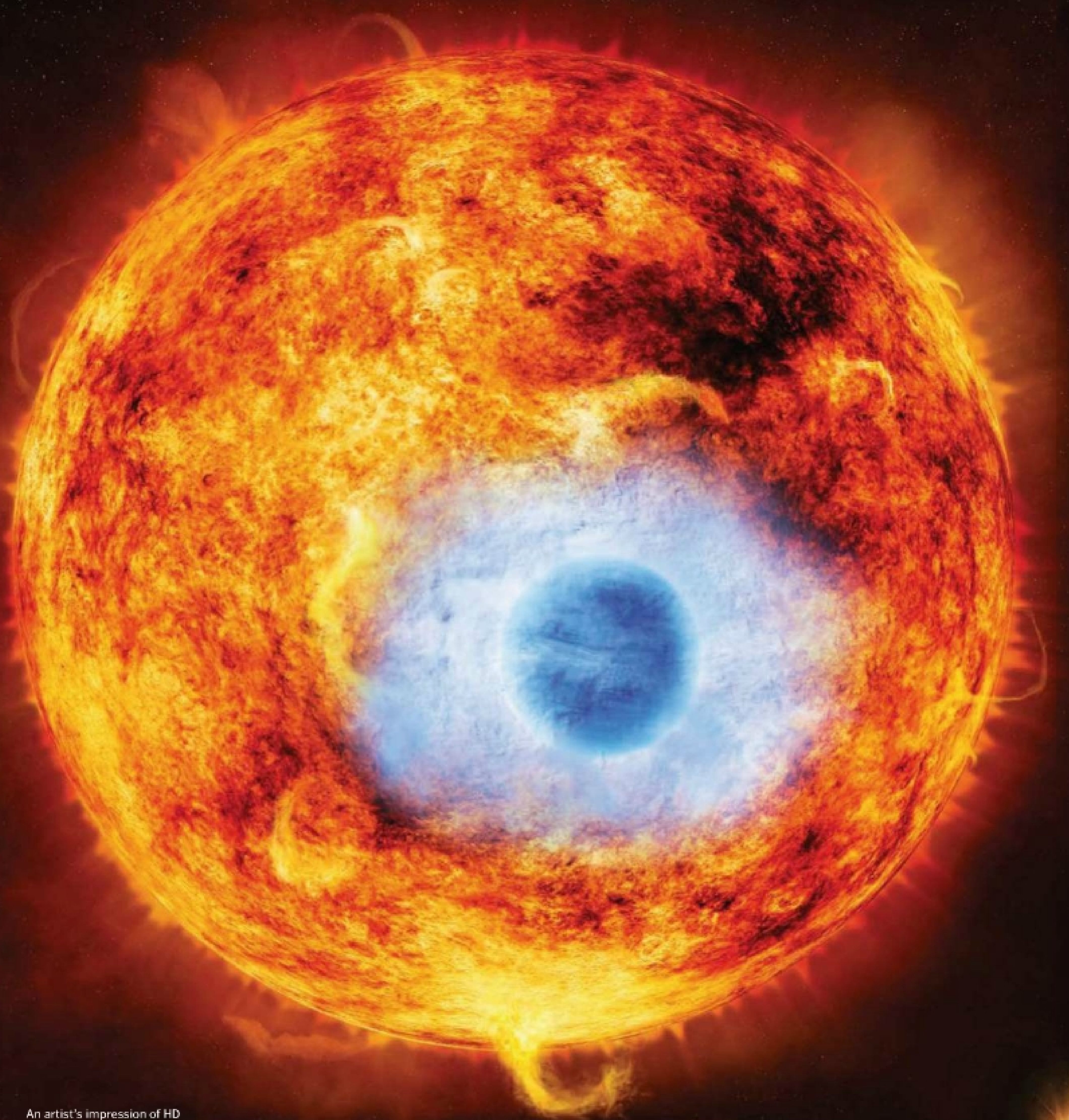
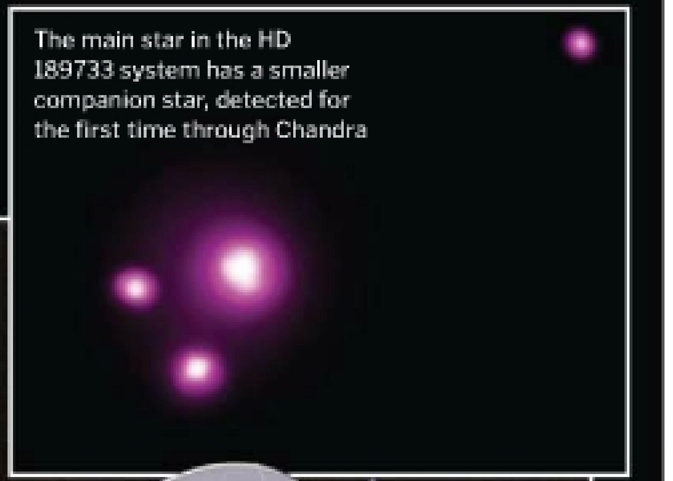
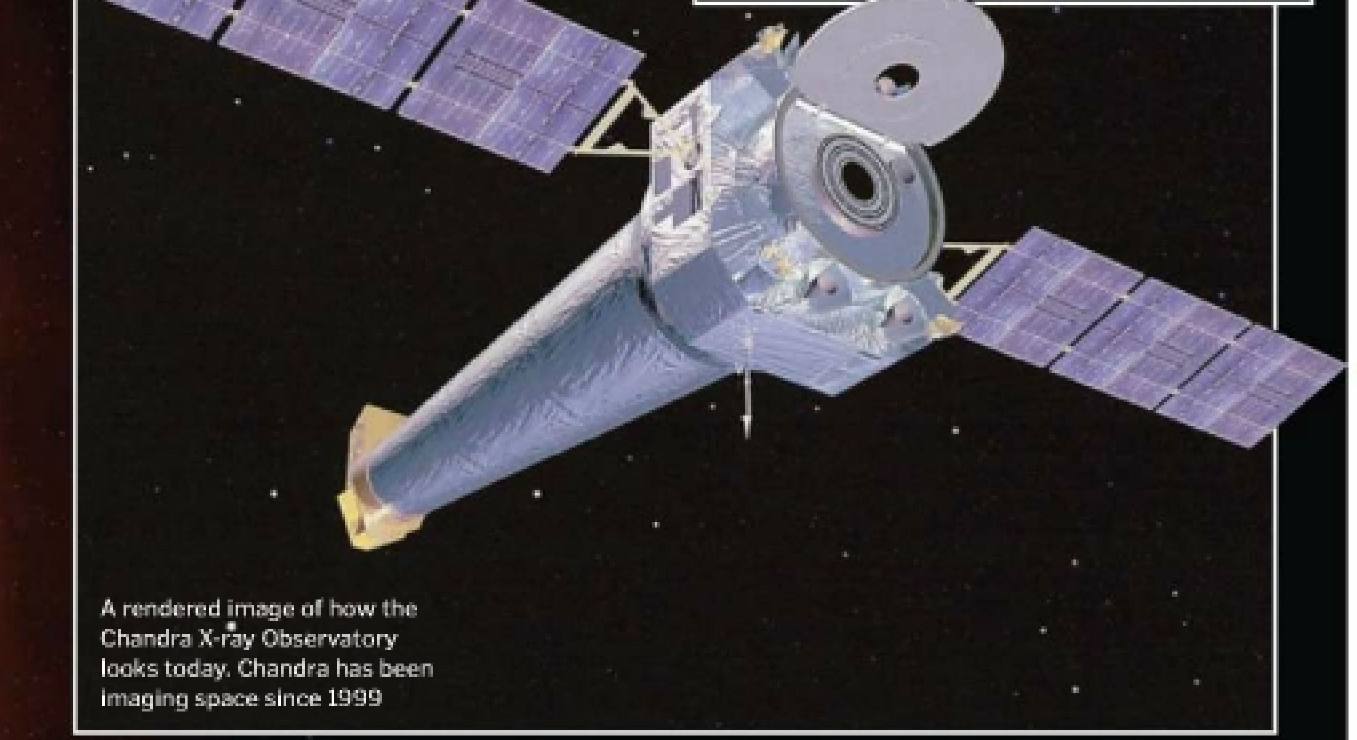


An artist's impression of HD 189733b, a blue, Jupiter-sized exoplanet orbiting its Sun-like star



The main star in the HD 189733 system has a smaller companion star, detected for the first time through Chandra



A rendered image of how the Chandra X-ray Observatory looks today. Chandra has been imaging space since 1999

Alien 'Jupiter' discovered

A Jupiter-like planet orbiting a star at close range is snapped with X-rays

For the first time ever NASA has imaged an exoplanet passing in front of its parent star with X-rays (see main image). The feat – which was achieved by NASA's Chandra X-ray Observatory – has been celebrated within the astronomical community as, up until now, exoplanets such as this one have only been captured using optical light.

Speaking on the breakthrough, Katja Poppenhaeger of the Harvard-Smithsonian Center for Astrophysics said: "Thousands of planet candidates have been seen to transit in only optical light. Finally being able to study one in X-rays is important because it reveals new information about the properties of an exoplanet."

Interestingly, closer analysis of the results has revealed that the planet, which currently has the rather technical name of HD 189733b, is akin to a hot version of our Solar System's Jupiter – but 30 times closer to its star than Earth to the Sun. This proximity means that the planet orbits its star once every 2.2 days and has a surface temperature of over 1,000 degrees Celsius (1,832 degrees Fahrenheit).

Further, studies of the exoplanet have shown that its blue colour is the result of a high presence of silicate particles in its atmosphere. NASA scientists believe this is because the planet's atmosphere rains silicate glass sideways within winds of over 7,000 kilometres (4,350 miles) per hour.

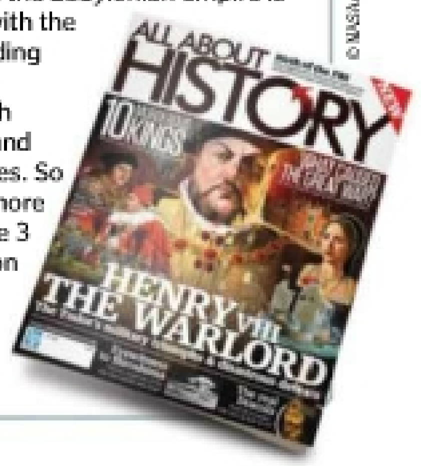
Moving forward, NASA intends to continue investigating the new planet and its system's main and companion stars, determining more about the relationship between them and how they influence one another.

Scientists grow heart

Scientists from the University of Pittsburgh, PA, have managed to grow a functioning mouse heart from pluripotent stem cells – adult stem cells that act like embryonic ones. The team achieved this by stripping a mouse heart of its cells and then replacing them with human stem cells. The result was that the heart began to beat again just as before. The team – who published the research results in the journal *Nature Communications* – said it could lead to induced pluripotent stem (iPS) cells being used in organ transplants in the future, while hearts and other major organs could also be made to test drugs in laboratories. Research team member Dr Lei Yang commented on the publication of the results: "Scientists have been looking to regenerative medicine and tissue engineering approaches to find new solutions for this important problem. The ability to replace a piece of tissue damaged by a heart attack, or perhaps an entire organ, could be very helpful for these patients."

New All About History lands!

If you ever wondered what life was like fighting under Henry VIII then the latest issue of **All About History** is for you. This month they've gone full-on Tudor to produce the definitive feature on this famous monarch's military record, with everything from his greatest triumphs to his most bitter defeats. This edition also counts down ten of the most murderous monarchs and talks to the last survivor from the Enola Gay which dropped the atomic bomb on Hiroshima. If all the blood and destruction gets too much, a feature on the Babylonian empire is the perfect antidote, with the city of Babylon – including those famous Hanging Gardens – detailed with stunning illustrations and some fascinating stories. So for all that and much more be sure to pick up issue 3 of **All About History**, on sale 22 August 2013, available from supermarkets and all good newsagents.



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“In answering why primordial soup is wrong you quickly get to the question ‘What is life?’”

Creation: The Origin Of Life/The Future Of Life **is available now priced £20 at all good bookshops.** ***Inside Science*** **airs every Thursday at 4.30pm on BBC Radio 4.**

The man inside science

Star of the BBC’s Inside Science, Adam Rutherford talks about the origins of life, what we can learn from a paper cut and the importance of non-stick frying pans

Tell us about your new book *Creation*.

The idea for the book spawned about ten years ago when I was still working in the lab. My beat has always been genetics and evolution in terms of being a journalist and two advances happened in molecular biology that I found extraordinarily interesting. The first is the origin of life. We have now got to a stage where, because of our understanding of the cell – of the mechanics of metabolism and how DNA works – we’ve got a pretty robust model of how life itself originated. So we can begin to test all of the basic principles of cells, what they do and how they could have come about.

The [second thing] is our ability to manipulate DNA in what we now call synthetic biology. That field has really blossomed over the last ten years. Now both those things are inherently related. The science of the origin of life is about reconstructing cells in the way we think it might have happened 4 billion years ago. And synthetic biology is essentially doing the same but just for specific purposes. So it produces cells that have a function that is useful to us. The modern era of molecular genetics has given birth to these two fields and I wanted to put them back-to-back.

Do you approach the origins of life in a chronological order?

Yes, kind of. I start off with a paper cut actually, as I want to get readers thinking about the monumental significance of the mundanity of living. That if you cut your finger, after a couple of days it is patched up and that, after a month or so, it is fully healed and, after a few months, it will be indistinguishable to how it had been before. That process, which is incredibly sophisticated and has taken researchers decades to fully understand, involves the birth of new cells. Those cells are not born from nothing – they are born from existing cells. And those cells were born from existing cells and so on until you get back to your first cell, which was a fertilised egg. And you can track that exact same process back in your parents and their parents and every member of our species, and on to every organism that has ever existed. So that cell which is patching up a little hole on your finger has a lineage, a direct ancestry which we can trace back 4 billion years to the first cell that ever existed. We call that cell ‘LUCA’ (Last Universal Common Ancestor) – the mother of everything that has ever lived.

Do you subscribe to a specific theory as to how LUCA was generated?

There are a few different models as to how LUCA came to be and I end up pinning my colours to a specific and [unorthodox] view. And that is not the culturally pervasive idea of the primordial soup. The reason that won’t work is because of physics. When you prime that soup so that interesting reactions will take place, they may well occur, but the problem is they won’t happen again. That is not what life does.

In answering why primordial soup is wrong you very quickly get to the question ‘What is life?’ – and interestingly there isn’t a definition. I have gone through the various ideas of what life is about, but there’s a fundamental underlying process that enables everything life does: life captures energy from the environment and uses it. I think that is the most basic test of what living things do. What I am talking about is how you get metabolism first.

So then you begin to look for a place where you might see naturally occurring chemistry that resembles the most fundamental energy-generating process that cells do, and these are deep-sea hydrothermal vents. It’s a really interesting model of how life might have begun.

What is your new radio show, *Inside Science*, all about?

It’s a new slot on Radio 4 where we wanted to reflect how science has changed over the past ten years. We wanted to be more reflective of how science works as a process. So in general we wanted to move away from merely looking at what studies had come out and instead look at how experiments develop, how scientists think and what the environment is like during the scientific method. We aim to detail the truth about the scientific process warts and all.

If there were one piece of technology you couldn’t live without what would it be?

I’m tempted to say the thing I’m holding right now – my smartphone – although that is so obvious. So I would say something like the toaster. Or the oven. What would we do if we couldn’t cook anything? In fact, that is a good answer. We evolved out of being able to digest raw food about 400,000 years ago, so without an oven or a toaster or a frying pan we would be absolutely shafted. I’m going to go for the non-stick frying pan!

What projects are you looking forward to?

Next week I’m filming a slot for BBC’s *The One Show* on genetically modified foods, where I shall be arguing Britain should be adopting GM crops. Following that I will be working on my second book, which I have just started writing. However, that’s going to have a two-year gestation period, so don’t hold your breath!

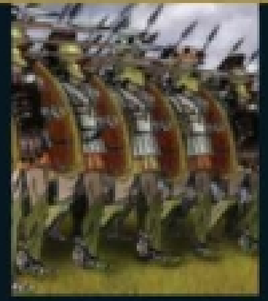
This day in history

12 September: How It Works issue 51 goes on sale, but what else happened on this day in history?

490 BCE

Greek victory

The Battle of Marathon concludes with the combined forces of Ancient Greece defeating the invading Persians.



1309

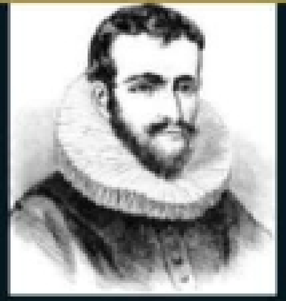
Battle for Gibraltar

The First Siege of Gibraltar takes place with Castile taking it from the Emirate of Granada.

1609

Up the Hudson

English explorer Henry Hudson begins a trip along the Hudson River in Canada, aboard the Halve Maen (Half Moon).



1846

Poetry in motion

Famous poet Elizabeth Barrett elopes with playwright Robert Browning.

1885

Walkover

In the 1885-1886 Scottish Cup, Arbroath defeat Bon Accord by 36 goals to 0.

1940

Ancient art

Well-preserved cave paintings dating from the Palaeolithic period are discovered in Lascaux, France.

1958

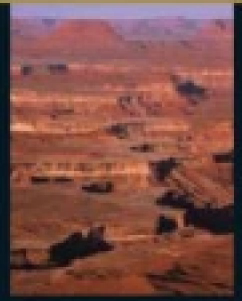
First chip

US electrical engineer Jack Kilby demonstrates the world’s first integrated circuit.

1964

Grand canyons

Canyonlands in Utah is granted official national park status.



2005

Disney in China

The Hong Kong branch of Disneyland opens for the first time.

2011

Lest we forget

The 9/11 Memorial is opened to the public, ten years after the terrorist attack took place.

10 COOL THINGS WE LEARNED THIS MONTH

Earth waved at Cassini

Last issue we revealed a rare photo of Earth, the Moon and Saturn captured by Cassini 1.5 billion kilometres (900 million miles) away. This issue we reveal the reverse picture. This mosaic is a collage of the photos shared by inhabitants of Earth on Twitter, Facebook, Flickr, Instagram, Google+ and email as part of the 'Wave at Saturn' mission. For the first time, we had advanced notice that an extraterrestrial photo would be taken so we could wave.

Talking while driving is dangerous

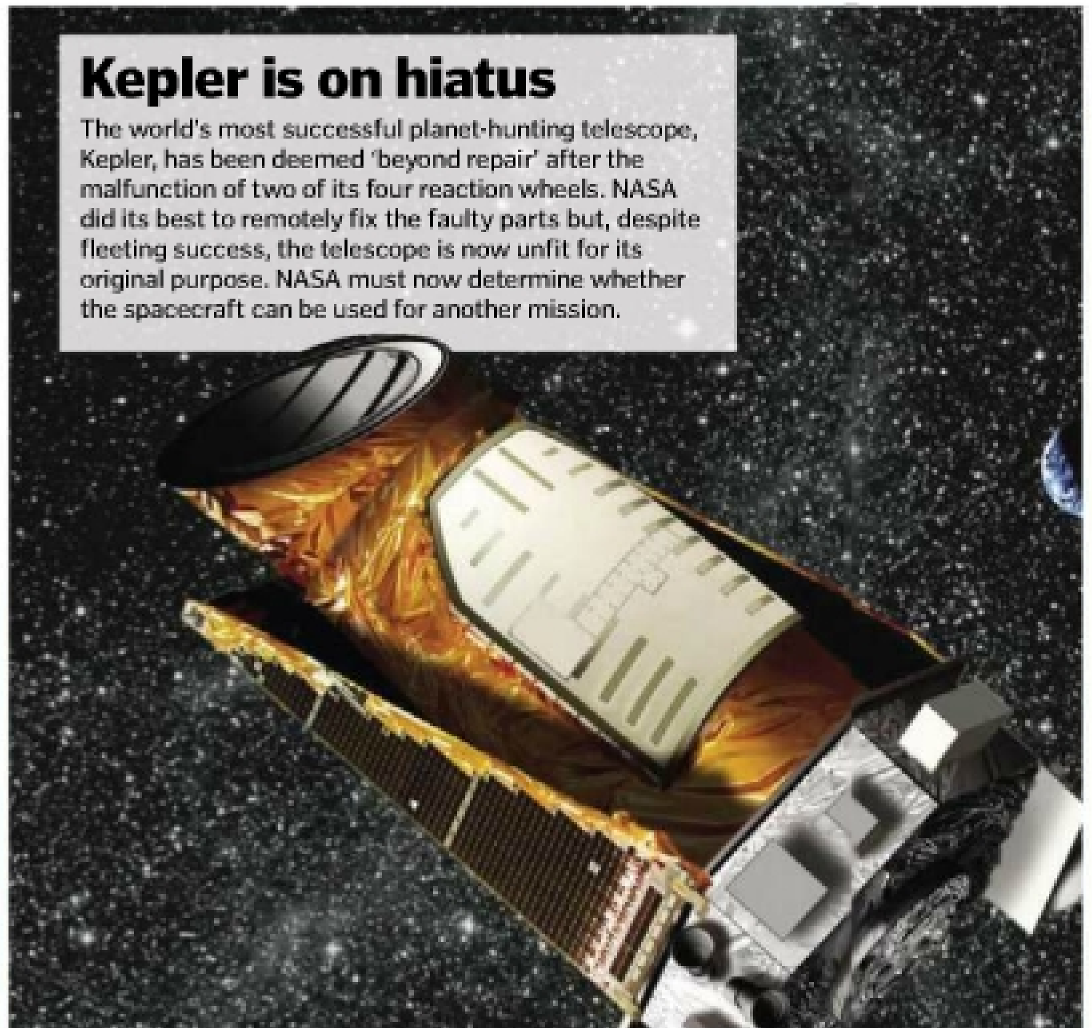
Although driving and using a hand-held device has been illegal in the UK since 2003, hands-free kits are legal. But now scientists researching the subject of distracted driving have suggested hands-free devices can be just as risky. Studies into 'cognitive load' indicate that when talking to someone we can't see, we subconsciously produce a mental picture of them, which demands extra brainpower and as a result deprives our other faculties.

'LEGO' holds the key to future manufacturing

A team at MIT has used the concept of a popular children's construction set to revolutionise the composite manufacturing process. By clipping together 2D shapes (such as crosses) made out of a super-light material, future material engineering could include the production of giant single units. Each piece – made up of millions of interlocking building blocks – would be tougher than current composites but much lighter, with huge potential for aircraft and spacecraft design, for instance.

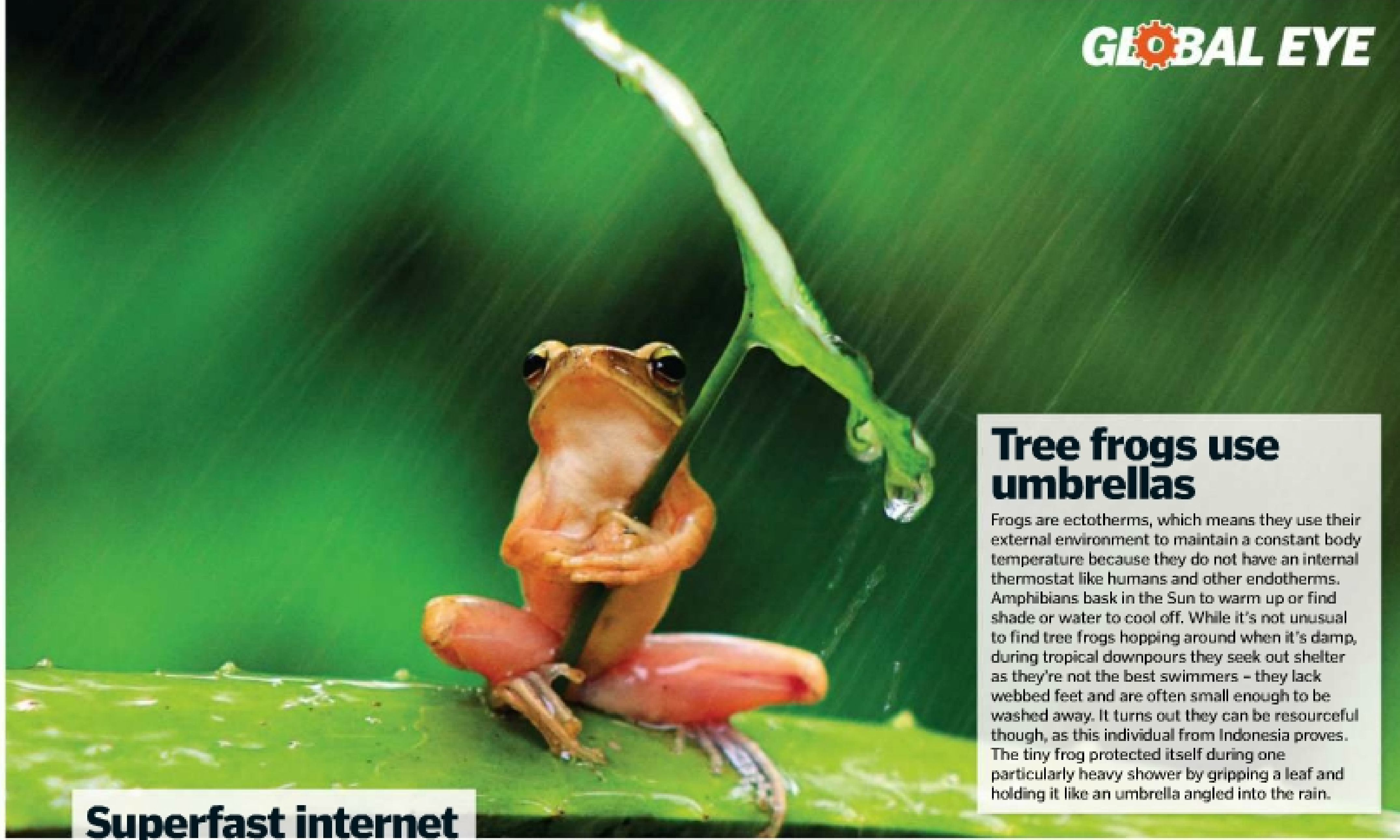
Sleepless nights increase temptation

Just one sleepless night can make you crave junk food the next day. A sleep study showed that activity in the area of the brain associated with the desire to eat was boosted in people who haven't had enough kip. In the area associated with judging and evaluating whether or not to eat, meanwhile, activity was reduced. This means that we find it harder to turn down the offer of indulgent snacks and treats after a bad night's sleep. This study could be used to explain the apparent link between sleeplessness and obesity.



Kepler is on hiatus

The world's most successful planet-hunting telescope, Kepler, has been deemed 'beyond repair' after the malfunction of two of its four reaction wheels. NASA did its best to remotely fix the faulty parts but, despite fleeting success, the telescope is now unfit for its original purpose. NASA must now determine whether the spacecraft can be used for another mission.

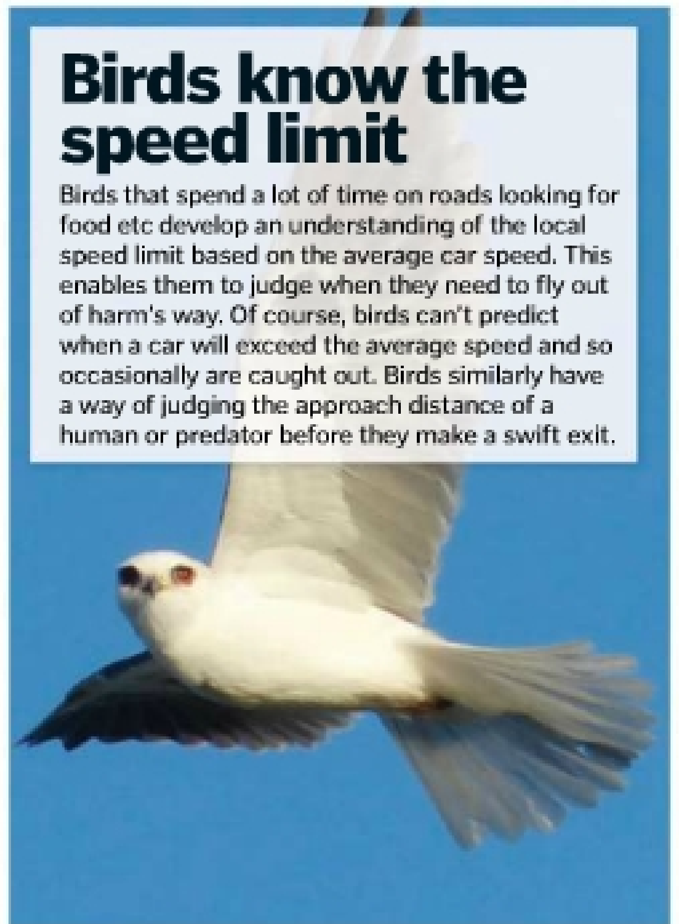


Tree frogs use umbrellas

Frogs are ectotherms, which means they use their external environment to maintain a constant body temperature because they do not have an internal thermostat like humans and other endotherms. Amphibians bask in the Sun to warm up or find shade or water to cool off. While it's not unusual to find tree frogs hopping around when it's damp, during tropical downpours they seek out shelter as they're not the best swimmers – they lack webbed feet and are often small enough to be washed away. It turns out they can be resourceful though, as this individual from Indonesia proves. The tiny frog protected itself during one particularly heavy shower by gripping a leaf and holding it like an umbrella angled into the rain.

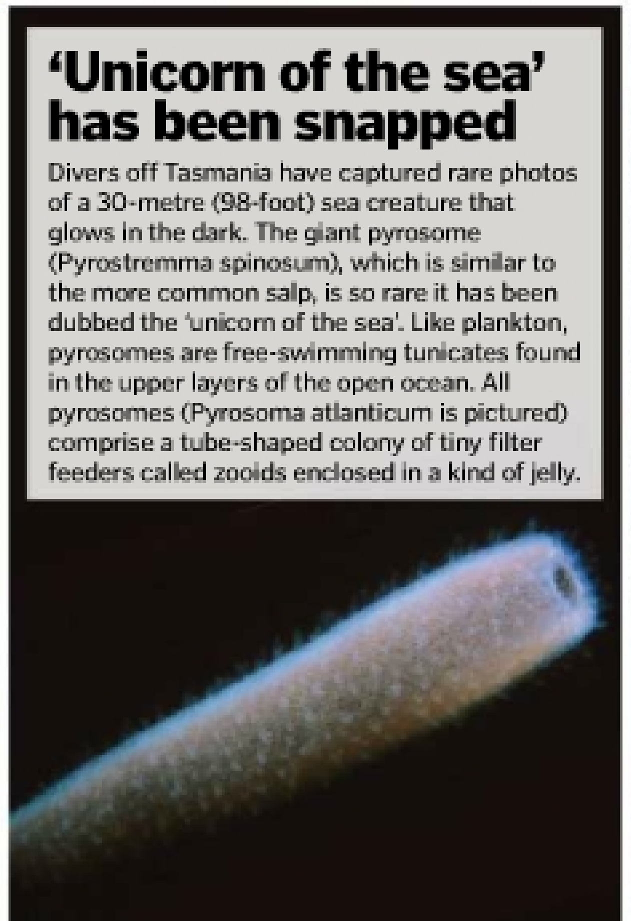
Superfast internet is coming to cars

Audi has become the first car manufacturer to include a 4G data connection in a production vehicle. The first model to debut this tech will be the Audi S3 Sportback (pictured here) and from November 2013 the full A3 range will feature superfast 4G/LTE data transfer. This development will enable high-quality in-car connectivity for lag-free web surfing while on the go.



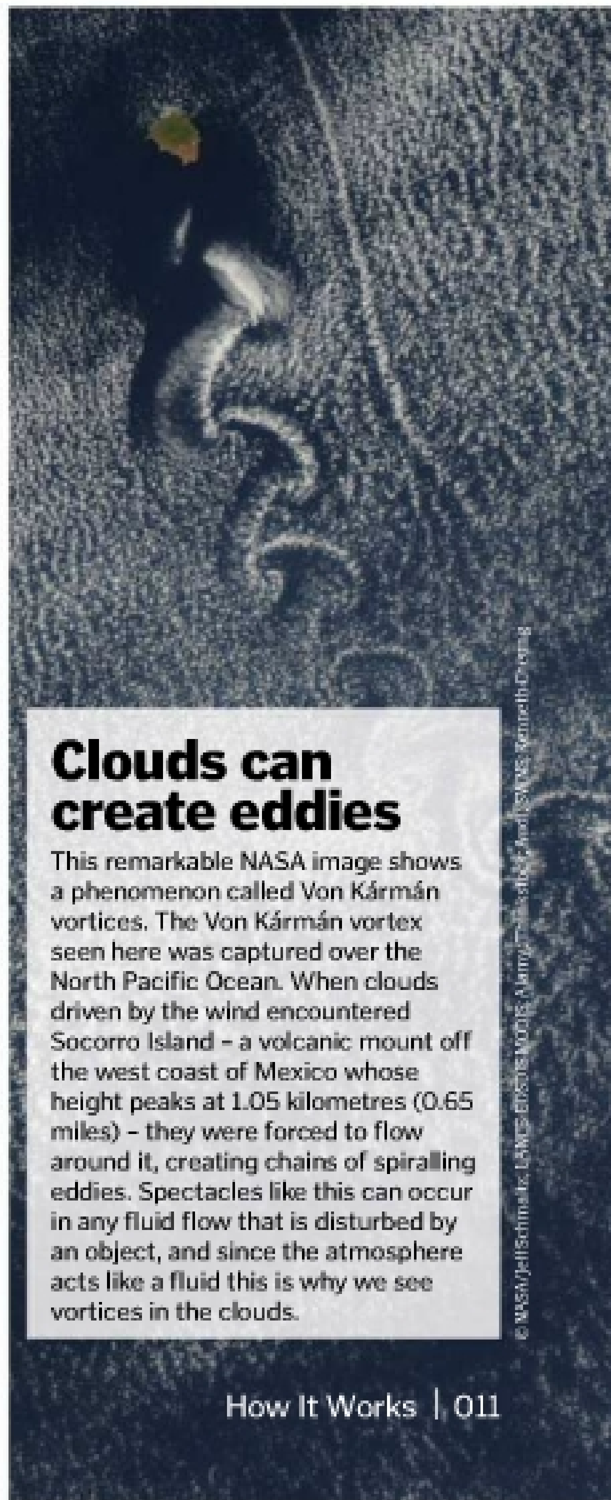
Birds know the speed limit

Birds that spend a lot of time on roads looking for food etc develop an understanding of the local speed limit based on the average car speed. This enables them to judge when they need to fly out of harm's way. Of course, birds can't predict when a car will exceed the average speed and so occasionally are caught out. Birds similarly have a way of judging the approach distance of a human or predator before they make a swift exit.



'Unicorn of the sea' has been snapped

Divers off Tasmania have captured rare photos of a 30-metre (98-foot) sea creature that glows in the dark. The giant pyrosome (Pyrostremma spinosum), which is similar to the more common salp, is so rare it has been dubbed the 'unicorn of the sea'. Like plankton, pyrosomes are free-swimming tunicates found in the upper layers of the open ocean. All pyrosomes (Pyrosoma atlanticum is pictured) comprise a tube-shaped colony of tiny filter feeders called zooids enclosed in a kind of jelly.



Clouds can create eddies

This remarkable NASA image shows a phenomenon called Von Kármán vortices. The Von Kármán vortex seen here was captured over the North Pacific Ocean. When clouds driven by the wind encountered Socorro Island – a volcanic mount off the west coast of Mexico whose height peaks at 1.05 kilometres (0.65 miles) – they were forced to flow around it, creating chains of spiralling eddies. Spectacles like this can occur in any fluid flow that is disturbed by an object, and since the atmosphere acts like a fluid this is why we see vortices in the clouds.

© NASA/Jeff Schmaltz, LANCE/EOSDIS MODIS; Alamy; Thinkstock; Audi; SPL; Kenneth Chung

5 TOP FACTS
ENERGY TRIVIA

Sunlight
1 The solar radiation beaming down on our planet from the Sun over just one hour carries more than enough energy to meet the global population's needs for a whole year.

Nuclear energy
2 Splitting just one kilogram (2.2 pounds) of uranium-235 nuclei in a fission reactor releases as much energy as over 2 million kilograms (4.4 million pounds) of coal in a power plant.

All in the mind
3 The brain is the body's most energy-greedy organ, taking up 20 per cent of the energy from your food. This energy fuels not only brain function but also its maintenance.

Solar diet
4 Fusion in the Sun's core converts mass into energy, causing it to lose about 4.3 billion kilograms (9.5 billion pounds) every second – still a tiny fraction of its total mass.

High-energy physics
5 A proton whizzing around the Large Hadron Collider has a comparable amount of kinetic energy to a mosquito – but this energy is concentrated in a much, much tinier body.

DID YOU KNOW? *A lightning bolt contains 5 billion joules of energy – enough to cook 100,000 slices of toast*

ENERGY EXPLAINED

Get back to basics and find out how energy underpins every process in the universe

On an intuitive level, we all know that energy is what makes things happen, causing the Sun to shine, allowing plants to grow, cooking food on a stove or making a basketball bounce. Whenever something heats up, cools down, moves, grows, makes a sound or changes in any way, it uses energy. And from taming fire to powering smartphones, human civilisation relies on our ability to manipulate energy. But pinning down exactly what energy *is* can be tricky.

Grab a textbook and you'll find energy described as 'the ability to do work'. Work in this context is defined as exerting a force on an object over a distance. Lifting a cardboard box off the ground constitutes work, however continuing to hold it there – although requiring effort on your part – is not work.

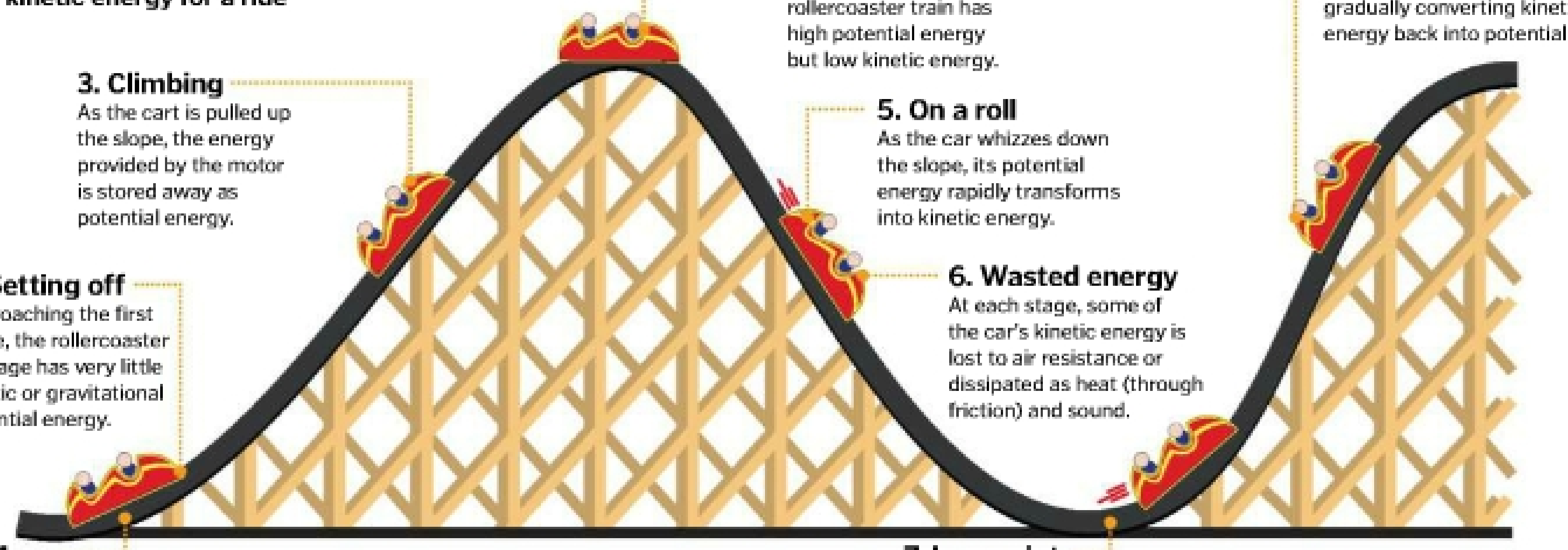
When work is done to an object, it gains energy. This energy is called kinetic energy if it's associated with the object's motion, as with a football speeding through the air after you kick it. When you pick up the box it is said to have gained potential energy, stored by virtue of its elevation above the ground. If you let go (mind your toes!), the box will fall, losing potential energy as it loses height, and gaining kinetic energy as it picks up speed.

One of energy's fundamental properties is that it cannot be created nor destroyed, only transformed from one type to another. Potential energy can turn into kinetic energy and vice versa limitless times. Further, mechanical, sound, heat, electromagnetic, light, chemical and nuclear energy can all be converted from one into the other.

But while you can't destroy energy, you can certainly waste it through inefficiency. When you drive a car, for example, chemical energy stored in the fuel is converted into first thermal energy and then kinetic energy which turns the car's wheels. But not all of the chemical energy released from the fuel goes into making the vehicle move. Some is converted to heat and sound, and some is used to displace air around the car – ie air resistance. Once this has occurred it's very hard to turn this wasted energy back into something useful.

Energy in a rollercoaster

Find out how a rollercoaster takes potential and kinetic energy for a ride



1. Mass
The rollercoaster cart's mass determines how much energy is required to move it, as well as how much potential energy it can store.

2. Setting off
Approaching the first slope, the rollercoaster carriage has very little kinetic or gravitational potential energy.

3. Climbing
As the cart is pulled up the slope, the energy provided by the motor is stored away as potential energy.

4. At the top
Edging slowly past the highest point, the rollercoaster train has high potential energy but low kinetic energy.

5. On a roll
As the car whizzes down the slope, its potential energy rapidly transforms into kinetic energy.

6. Wasted energy
At each stage, some of the car's kinetic energy is lost to air resistance or dissipated as heat (through friction) and sound.

7. Low point
At the bottom of the slope, the car's potential energy is at its minimum while its kinetic energy peaks.

8. Back up
The rollercoaster carriage slows as it climbs the next peak, gradually converting kinetic energy back into potential.

Einstein's big idea

In 1905, Einstein revolutionised physics with a jaw-dropping revelation: matter and energy are one and the same. This fact is immortalised in the world's most famous equation: $E=mc^2$. Under the right conditions, energy can be converted into matter and vice versa. This energy comes from the ultra-strong bonds holding protons and neutrons together in atomic nuclei. The c in the equation represents the speed of light – about 1.13 billion kilometres (700 million miles) per hour – so even an object with tiny mass contains a huge amount of energy. If you could turn every atom of a paperclip into energy, you would release as much energy as the atomic bomb that obliterated Hiroshima in 1945. Doing so would, however, require extreme temperature and pressure conditions that are impossible on Earth.

c
The speed of light in a vacuum: ie around 300,000,000m/s (983,600,000ft/s).

$$E = mc^2$$

E
E is energy, which is measured in joules.

m
m represents mass, measured in kilograms.

Throughout history we have relied on different means to get hold of usable energy, from early windmills to coal-burning steam engines. Today, we consume energy mainly as petroleum, natural gas and electricity. We tap into the energy stored in the chemical bonds of petrol or natural gas by burning these fuels, whether inside a boiler or an engine, etc.

Electricity, on the other hand, is a handy way of transporting energy converted from various more cumbersome sources into our homes or workplaces. A wind turbine, for instance, converts kinetic energy, while a nuclear reactor exploits the energy locked in atomic nuclei, generating first thermal and then electrical energy. Once inside our home, electricity can be used for heating, cooking, lighting and running all of our appliances and gadgets.

Energy is measured in joules (J), with one joule being the energy needed to apply a force of one newton (N) over one metre (3.2 feet).

In practice, a variety of different units are commonly used to measure energy in its multitude of different forms. The chemical energy in food is measured in calories – the amount it takes to raise the temperature of one gram of water by one degree Celsius. Your electricity bill, in comparison, measures the electrical energy you have used in kilowatt-hours (kWh). For some context, one kilowatt-hour is enough to run one washing machine cycle or watch seven hours of TV.

Conservation of energy

One of our universe's most basic principles, the law of conservation of energy states that energy can be neither created nor destroyed. That is, the amount of energy in a closed system is fixed. It can, however, be transferred from one object into another, and converted from one form to another.

Although we discuss energy production, you can't create new energy – only convert existing energy to a different usable form. A photovoltaic panel, for instance, taps into the Sun's radiant energy, converting it to usable electrical energy.

Likewise, the energy that we use doesn't disappear – it just changes into other forms. Switch on your television and the heat, sound and light energy emanating from the set gradually leak back into the environment.

Throughout history, numerous inventors have attempted to design and build perpetual motion machines that would give out more energy than was put in, but conservation of energy has made such inventions impossible – at least thus far!

> "Potential energy has its roots in the force acting between two objects and the distance between them"

RECORD BREAKERS
WATER INTO WATTS

98.3

MOST PRODUCTIVE POWER STATION
The Itaipu hydroelectric dam between Brazil and Paraguay generates more energy than any other facility: over 98TWh. Water flows through it at up to 62,000 cubic metres (2.2 million cubic feet) per second.

DID YOU KNOW? On average, a US inhabitant uses over ten times as much energy than someone living in India

POTENTIAL VS KINETIC ENERGY

The simplest way to classify energy is by dividing it into kinetic energy and potential energy. This distinction is, however, not enough to fully describe the different ways in which an object or a system can possess energy. Hence we have nine major forms of energy.

Kinetic energy is associated with motion. From an oxygen molecule through to a planet, the more mass an object has and the faster it moves, the greater its kinetic energy. The motion of different types of objects gives rise to different forms of kinetic energy.

Potential energy has its roots in the force acting between two objects and the distance between them. For example, the potential energy of a rock on top of a hill comes from the gravitational force between Earth and the rock. The more massive the rock, and the greater its height, the bigger its potential energy. Different forces give rise to potential energy under different names, as we see here.

Sound

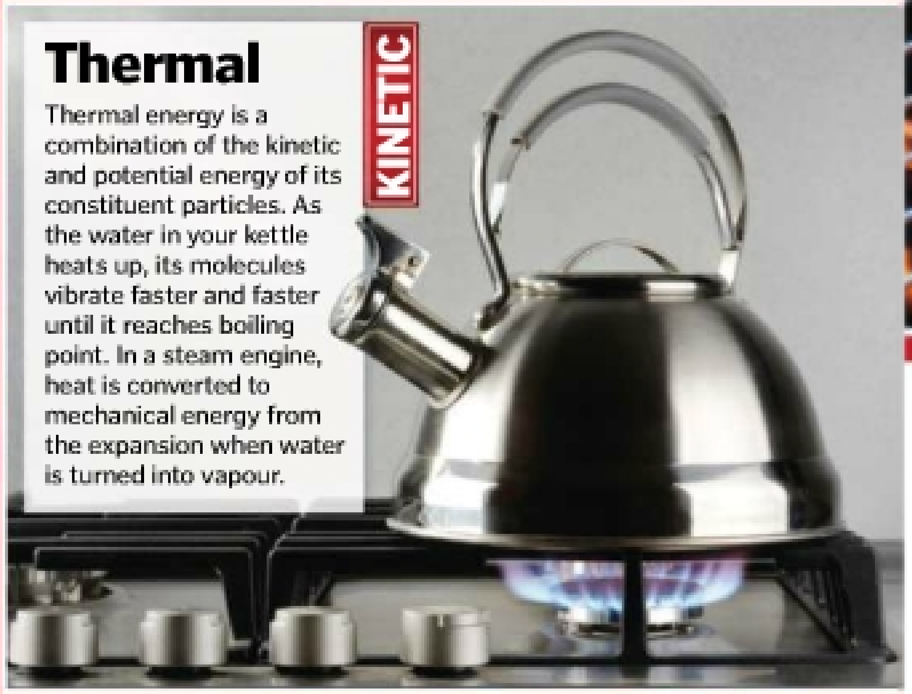
KINETIC

Sound energy is all about vibrations. Strum a guitar string and it vibrates. This motion propagates through the air, oscillating the molecules back and forth. When the wave reaches your ear, your eardrum vibrates in turn and your brain interprets the sound. We rarely use sound waves to do work but rather as a means to communicate or entertain.

Kinetic

KINETIC

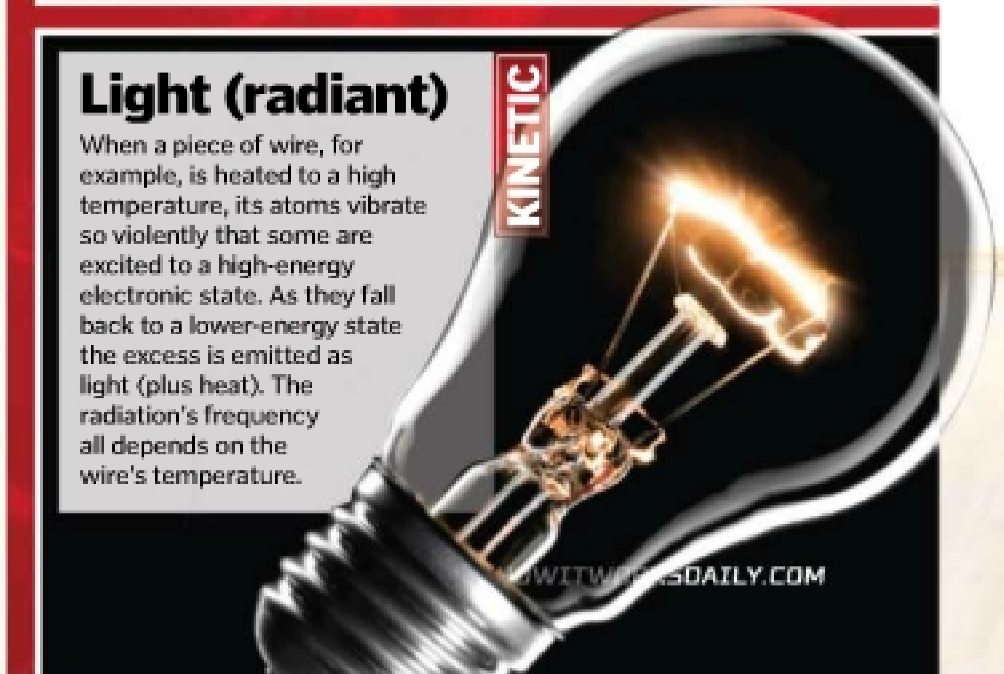
While sound, light and heat are all forms of kinetic energy, the term kinetic energy can also refer to the motion energy of objects on the macro scale – as opposed to invisible vibrations of tiny particles. We therefore use kinetic energy to talk about motion energy that we can see – for example, associated with a moving car or person.



Thermal

KINETIC

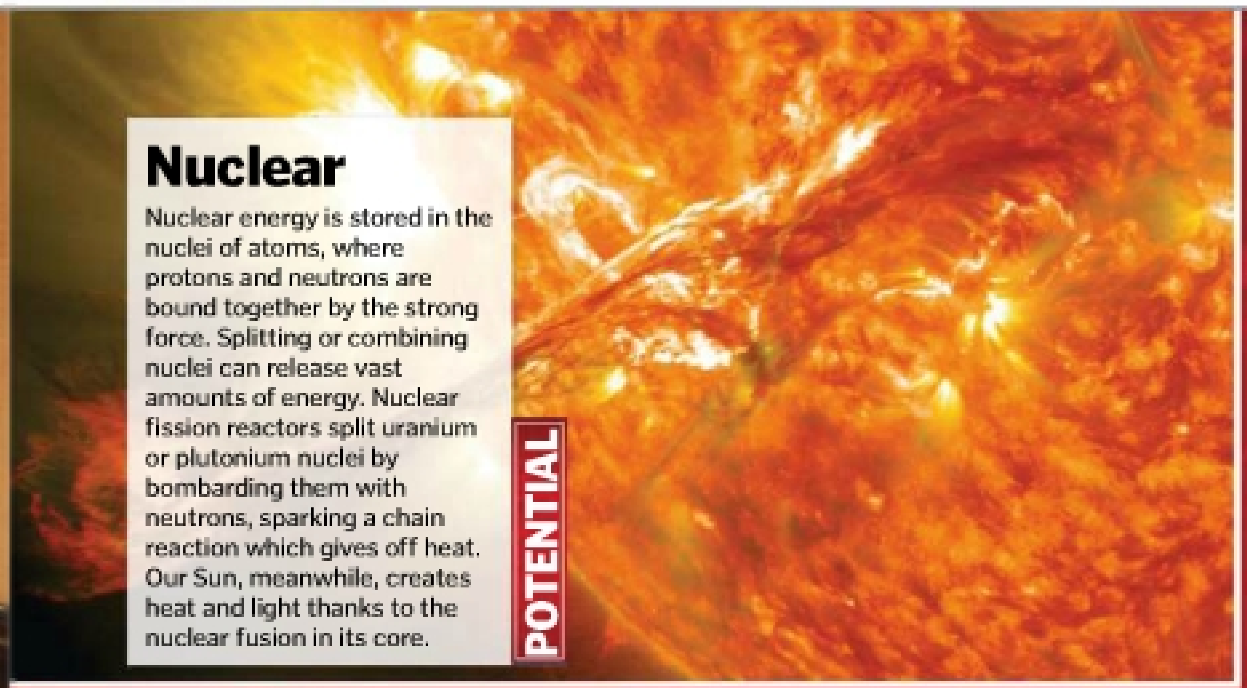
Thermal energy is a combination of the kinetic and potential energy of its constituent particles. As the water in your kettle heats up, its molecules vibrate faster and faster until it reaches boiling point. In a steam engine, heat is converted to mechanical energy from the expansion when water is turned into vapour.



Light (radiant)

KINETIC

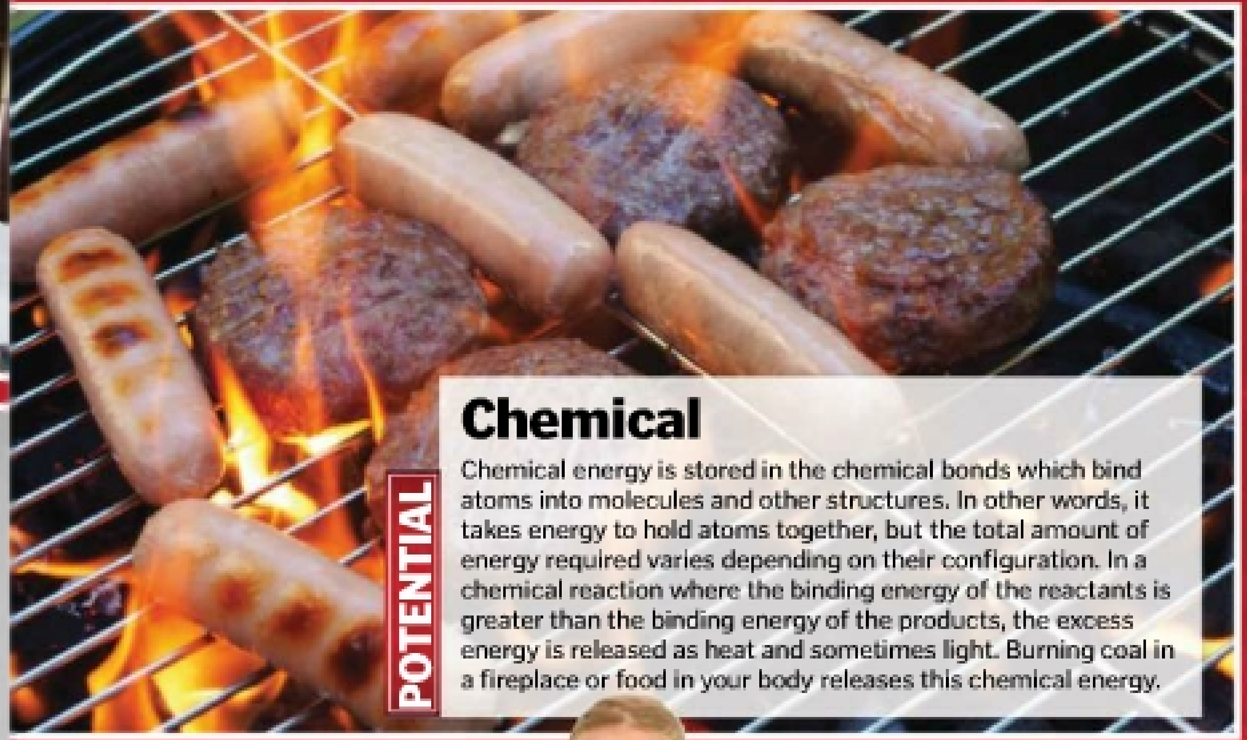
When a piece of wire, for example, is heated to a high temperature, its atoms vibrate so violently that some are excited to a high-energy electronic state. As they fall back to a lower-energy state the excess is emitted as light (plus heat). The radiation's frequency all depends on the wire's temperature.



Nuclear

POTENTIAL

Nuclear energy is stored in the nuclei of atoms, where protons and neutrons are bound together by the strong force. Splitting or combining nuclei can release vast amounts of energy. Nuclear fission reactors split uranium or plutonium nuclei by bombarding them with neutrons, sparking a chain reaction which gives off heat. Our Sun, meanwhile, creates heat and light thanks to the nuclear fusion in its core.



Chemical

POTENTIAL

Chemical energy is stored in the chemical bonds which bind atoms into molecules and other structures. In other words, it takes energy to hold atoms together, but the total amount of energy required varies depending on their configuration. In a chemical reaction where the binding energy of the reactants is greater than the binding energy of the products, the excess energy is released as heat and sometimes light. Burning coal in a fireplace or food in your body releases this chemical energy.

Elastic

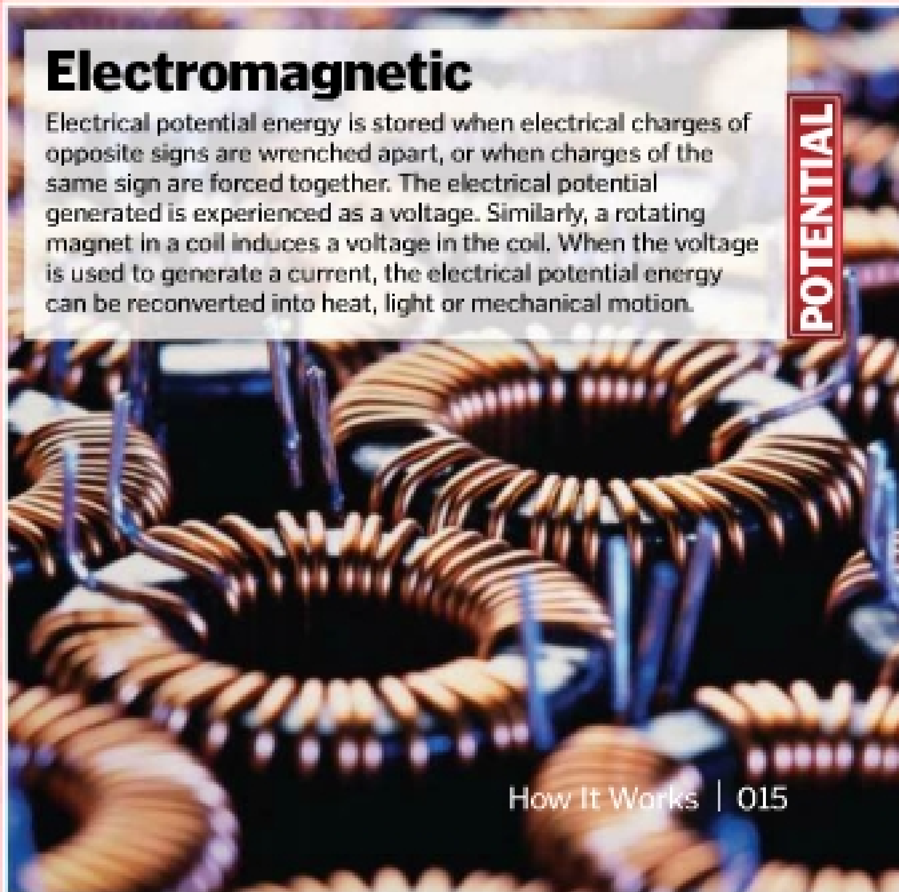
POTENTIAL

Elastic energy is the potential energy stored when an object's shape or volume is distorted – for example, when you jump on a trampoline. As the trampoline returns to its original shape, it propels you into the air, converting potential energy into kinetic energy. Not all materials have the same capacity to store elastic energy; a rubber band, for instance, can store more than a piece of string.

Gravitational

POTENTIAL

Gravitational energy stems from the gravitational field around our planet (and other bodies). It arises, for example, when a skier rides a ski lift up a mountain slope. The higher the skier travels, the more potential energy is stored up. Once they set off down the slope, this stored energy is transformed into kinetic energy as they speed up down the slope.



Electromagnetic

POTENTIAL

Electrical potential energy is stored when electrical charges of opposite signs are wrenched apart, or when charges of the same sign are forced together. The electrical potential generated is experienced as a voltage. Similarly, a rotating magnet in a coil induces a voltage in the coil. When the voltage is used to generate a current, the electrical potential energy can be reconverted into heat, light or mechanical motion.

"The simple act of making a piece of toast requires mastery of a large number of energy transformations"

STRANGE BUT TRUE
JOULE MAKER

Which phenomenon releases the most energy?

A A human sneeze B A hurricane C An atom bomb

Answer:
A hurricane can release up to 10^{19} joules of energy in a day – a million times as much as an atom bomb like the one dropped on Hiroshima. Though sneezing expels droplets at high speed, the energy involved is tiny by comparison.

DID YOU KNOW? The tips of a spinning wind turbine can travel as fast as 290km/h (180mph)

HOW IS ENERGY TRANSFERRED?

Next time you take a hot shower, drive to work or plug in a laptop, spare a thought for the science that brings energy on demand into your home.

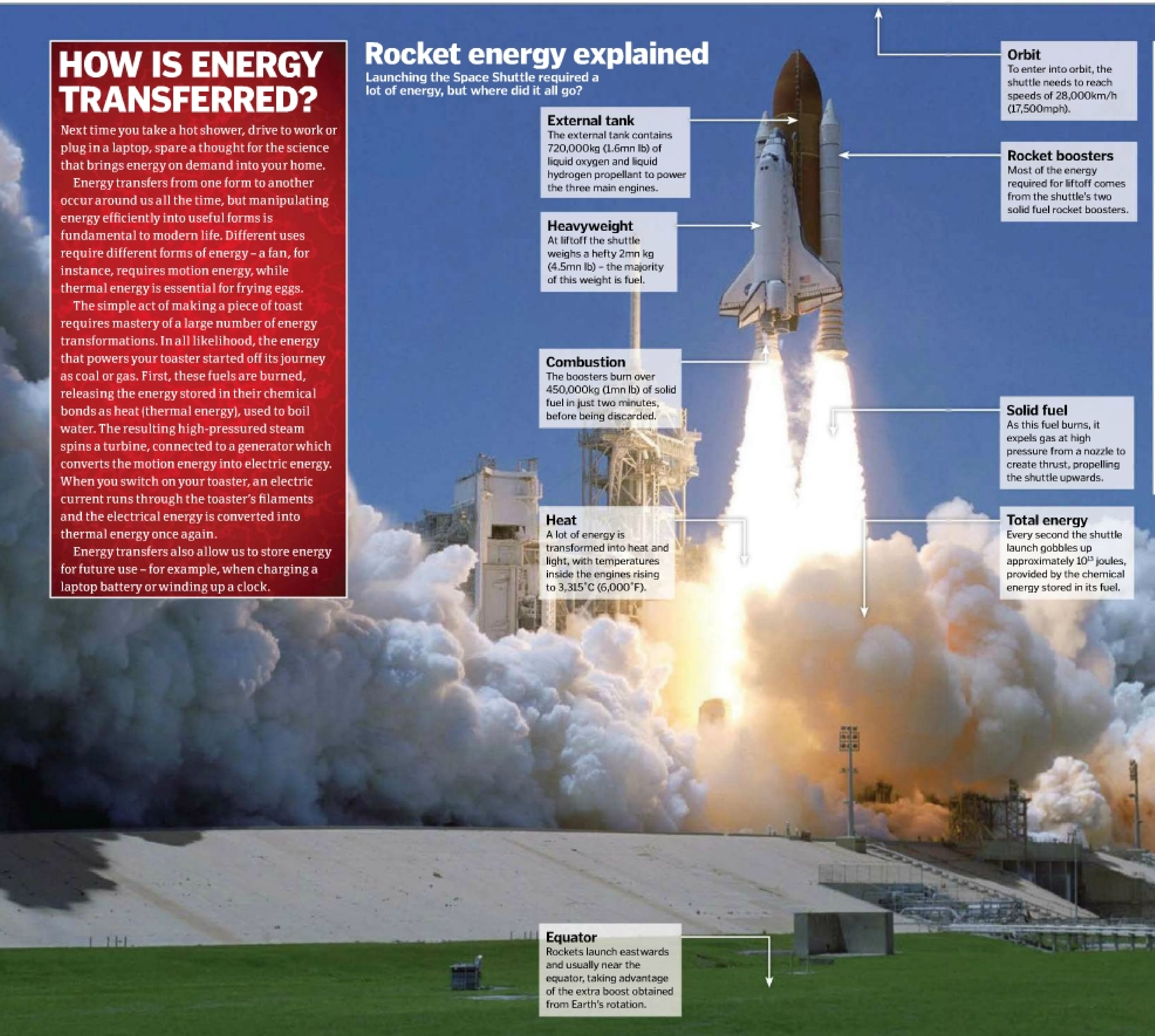
Energy transfers from one form to another occur around us all the time, but manipulating energy efficiently into useful forms is fundamental to modern life. Different uses require different forms of energy – a fan, for instance, requires motion energy, while thermal energy is essential for frying eggs.

The simple act of making a piece of toast requires mastery of a large number of energy transformations. In all likelihood, the energy that powers your toaster started off its journey as coal or gas. First, these fuels are burned, releasing the energy stored in their chemical bonds as heat (thermal energy), used to boil water. The resulting high-pressured steam spins a turbine, connected to a generator which converts the motion energy into electric energy. When you switch on your toaster, an electric current runs through the toaster's filaments and the electrical energy is converted into thermal energy once again.

Energy transfers also allow us to store energy for future use – for example, when charging a laptop battery or winding up a clock.

Rocket energy explained

Launching the Space Shuttle required a lot of energy, but where did it all go?



External tank
The external tank contains 720,000kg (1.6mn lb) of liquid oxygen and liquid hydrogen propellant to power the three main engines.

Heavyweight
At liftoff the shuttle weighs a hefty 2mn kg (4.5mn lb) – the majority of this weight is fuel.

Combustion
The boosters burn over 450,000kg (1mn lb) of solid fuel in just two minutes, before being discarded.

Heat
A lot of energy is transformed into heat and light, with temperatures inside the engines rising to 3,315°C (6,000°F).

Equator
Rockets launch eastwards and usually near the equator, taking advantage of the extra boost obtained from Earth's rotation.

Orbit
To enter into orbit, the shuttle needs to reach speeds of 28,000km/h (17,500mph).

Rocket boosters
Most of the energy required for liftoff comes from the shuttle's two solid fuel rocket boosters.

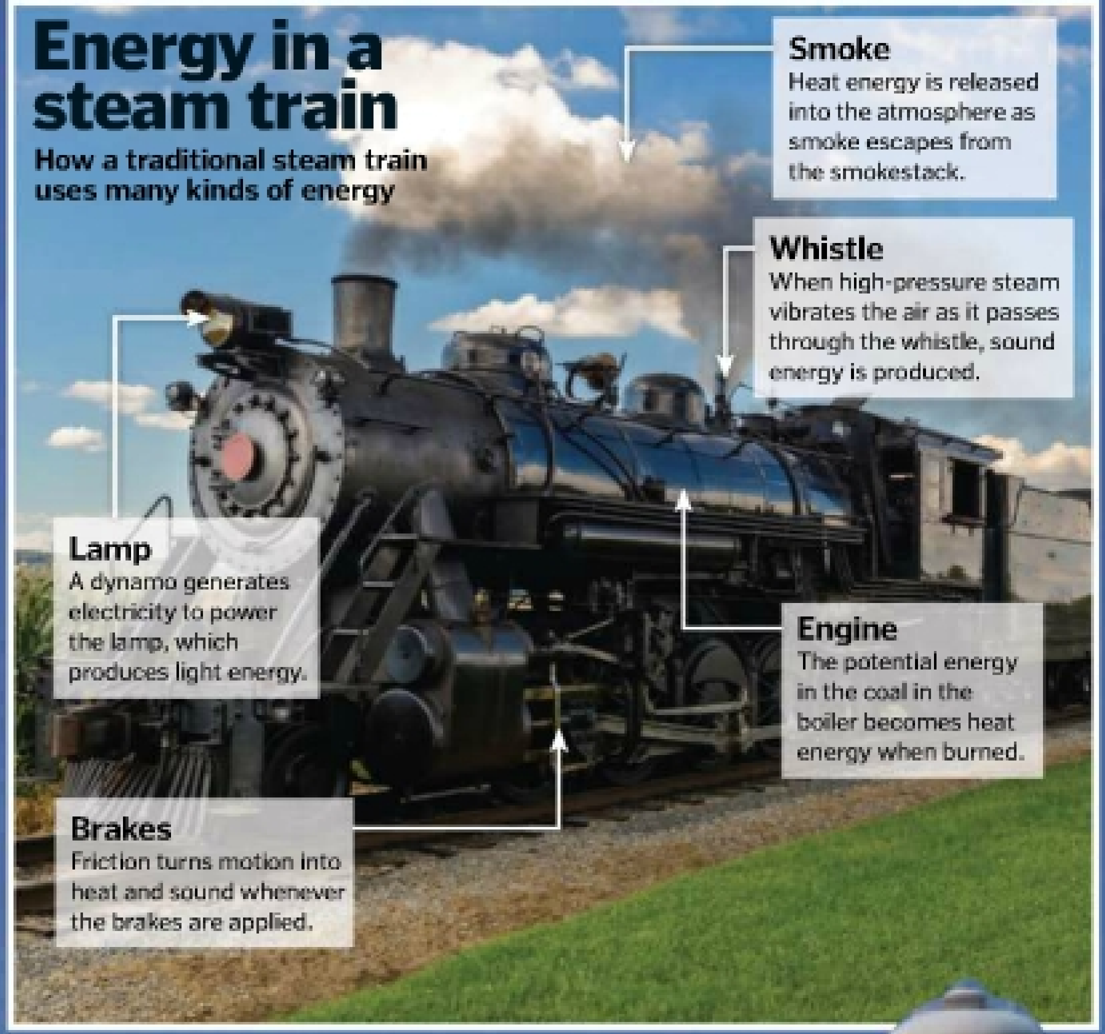
Solid fuel
As this fuel burns, it expels gas at high pressure from a nozzle to create thrust, propelling the shuttle upwards.

Total energy
Every second the shuttle launch gobbles up approximately 10^{13} joules, provided by the chemical energy stored in its fuel.

Sound
Exhaust leaving the shuttle creates vibrations and sound volumes up to a deafening 220dB.

Energy in a steam train

How a traditional steam train uses many kinds of energy



Smoke
Heat energy is released into the atmosphere as smoke escapes from the smokestack.

Whistle
When high-pressure steam vibrates the air as it passes through the whistle, sound energy is produced.

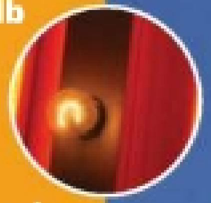
Lamp
A dynamo generates electricity to power the lamp, which produces light energy.

Engine
The potential energy in the coal in the boiler becomes heat energy when burned.

Brakes
Friction turns motion into heat and sound whenever the brakes are applied.

How energy transforms

1 Photosynthesis
Light energy is essential to plants, enabling them to convert carbon dioxide and water into glucose, thus turning radiant into chemical energy. Plants then use respiration to extract the glucose's chemical energy.



2 Filament light bulb
As electric current runs through the bulb's filament, electrical energy is changed into light energy. But traditional bulbs convert only ten per cent of incoming energy into visible light – the rest is wasted as heat.

3 Digestion
Your stomach breaks down your food to access the chemical energy stored inside sugars, fats and carbohydrates. Your muscles convert this energy into movement, generating thermal energy in the process.

4 Tennis
Whacking a tennis ball causes the ball to travel in the direction of the racket, absorbing energy from the player's arm as well as the energy imparted onto the ball by your opponent's last shot.

5 Speaker
Inside a speaker, pulses of electrical energy running through an electromagnet change its magnetic field. This causes a permanent magnet to vibrate back and forth emitting sound energy.

> "Nuclear fusion – the process that powers the Sun – could one day be a source of unlimited clean energy"

GOING GREEN

At any given moment, mankind is using roughly 15 terawatts of power – enough to run around 3 trillion iPads. Humans across the globe consume a total of around 500 exajoules (ie 10^{18} joules) of energy each year, and are expected to use over 50 per cent more by 2040. But our energy use is shockingly inefficient: in the US alone, an estimated 58 per cent of energy is wasted, mostly as unwanted heat.

The majority of our energy currently comes from fossil fuels, but as reserves of oil, gas and coal grow short – and concerns about global warming grow ever-more pressing – renewable energy is on the rise. Renewable sources currently meet around 16 per cent of the world's energy needs, harnessing energy from the Sun, wind, tides, biomass or geothermal heat.

For wind, tidal or hydroelectric power this involves harvesting kinetic energy and transforming it into electric energy. A hydroelectric dam, for instance, takes advantage of the potential energy of the moving water which it traps. As water gushes through the dam, its kinetic energy is captured by spinning turbines. In turn these use magnets to convert motion energy into an electrical current.

Inside the ASDEX Upgrade Fusion Reactor (Axially Symmetric Divertor Experiment) in Germany, where plasma for fusion reactions is made

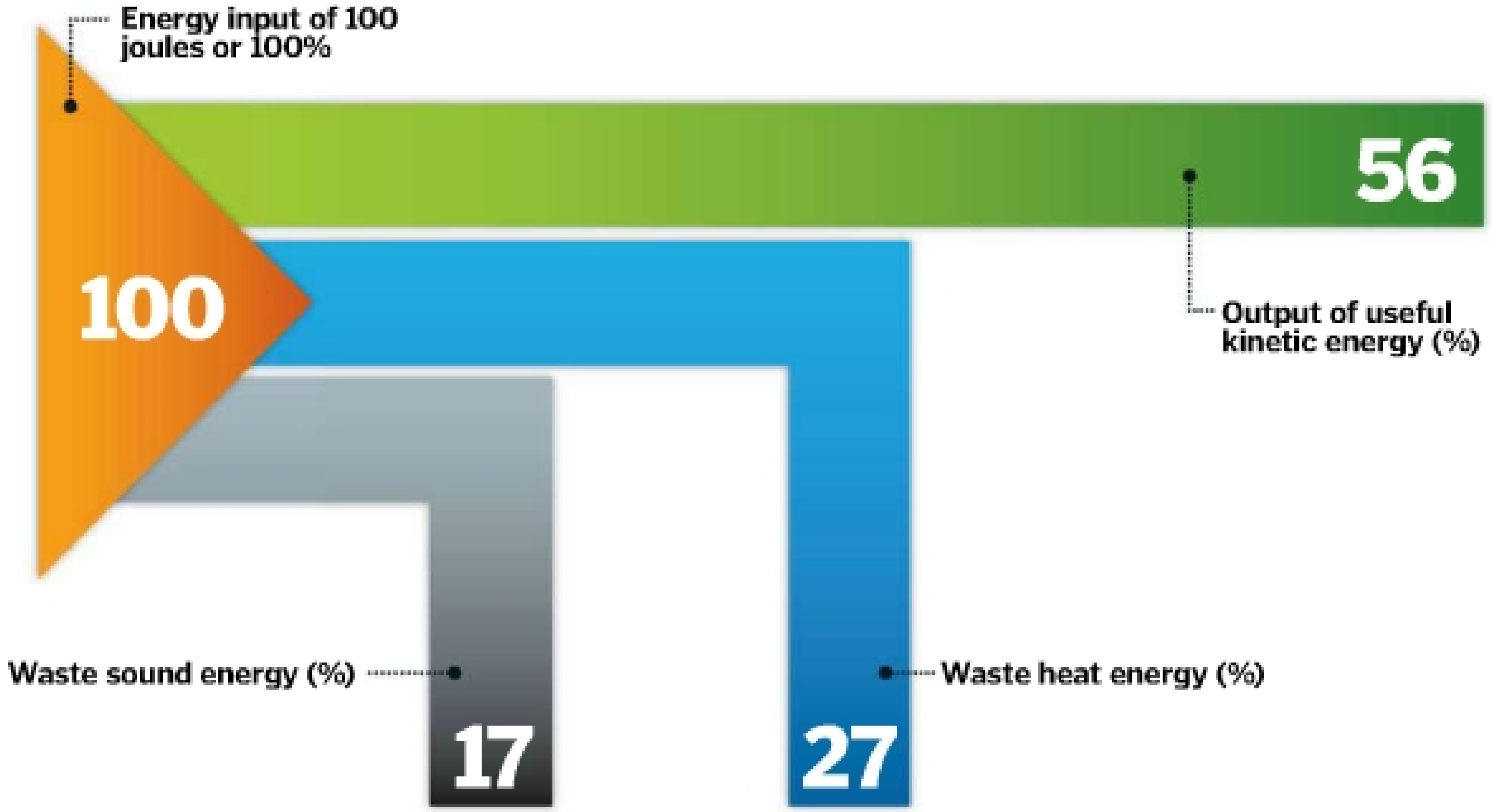
Fuelling the future

Meeting our planet's growing energy needs in a sustainable way is a tough challenge. Nuclear fusion – the process that powers the Sun – could one day be a source of practically unlimited, cheap, clean energy on Earth. The challenge, however, is creating the intense pressure and temperature conditions needed to coax hydrogen atoms into fusing and releasing some of their nuclear energy.

Cars of the future may fill up on biodiesel, ethanol or vegetable oil, or use electricity from a new source: hydrogen fuel cells. These combine hydrogen and oxygen to form water, exploiting the chemical energy released.

Visualising efficiency

No energy transfer can be 100 per cent efficient. This flow diagram illustrates the energy transfers at work inside an electric motor. With an energy input of 100 joules, the motor turns 56 joules into usable kinetic energy – in other words, it has an efficiency of 56 per cent. The remaining energy is wasted as sound and heat. This information allows engineers to pinpoint which parts of a process can be improved to make efficiency gains.



Energy input of 100 joules or 100%
100
56
Output of useful kinetic energy (%)
Waste sound energy (%)
17
Waste heat energy (%)
27

KEY DATES

ENERGY OVER TIME

1775 James Watt patents improvements on the steam engine, ushering in the Steam Age.

1830s Building on Michael Faraday's work on electromagnetism, electric generators and motors are invented.

1848 The first modern oil well is drilled in Azerbaijan. By the early-1900s it accounts for half of global production.

1945 The US detonates the first nuclear bomb, creating a blast equal to about 20 kilotons of TNT (or 84 terajoules).

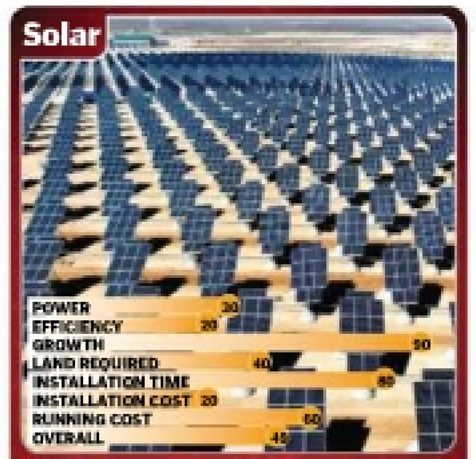
2005 The Kyoto Protocol comes into force, with 192 parties committed to limiting or reducing CO_2 emissions.

DID YOU KNOW? A person doing hard manual labour produces roughly enough energy to power a 100W light bulb

Renewables showdown

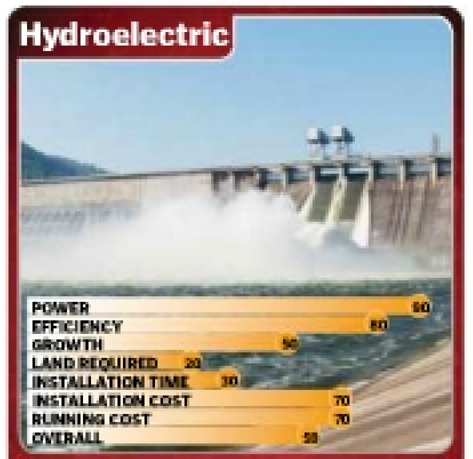
See how four major renewable energy sources square up

Solar



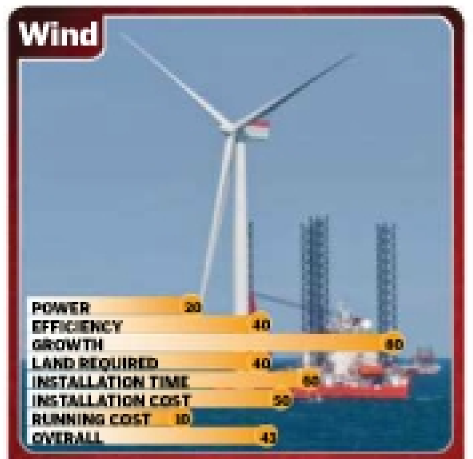
Solar energy is collected by photovoltaic cells, which transform light energy into electricity or thermal energy. Although the Sun provides limitless energy, the cells are quite inefficient and expensive.

Hydroelectric



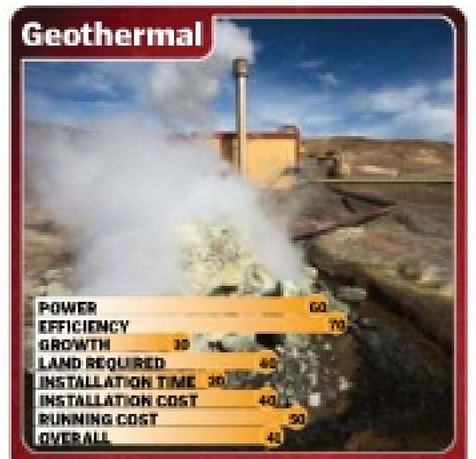
Hydropower harnesses the kinetic energy of moving water and is the largest source of renewable energy. But building a hydropower station requires damming off a river, which can harm the local environment.

Wind



Wind turbines capture the kinetic energy of the wind and convert it into electricity. Relatively efficient and cheap to install, wind energy is a fast-growing business, though some think wind farms are ugly.

Geothermal



Geothermal power plants gather the heat produced at Earth's core. The catch is that this energy must find its own way to the surface, meaning geothermal power is limited to relatively few locations, eg Iceland.

Iceland's renewable energy jackpot

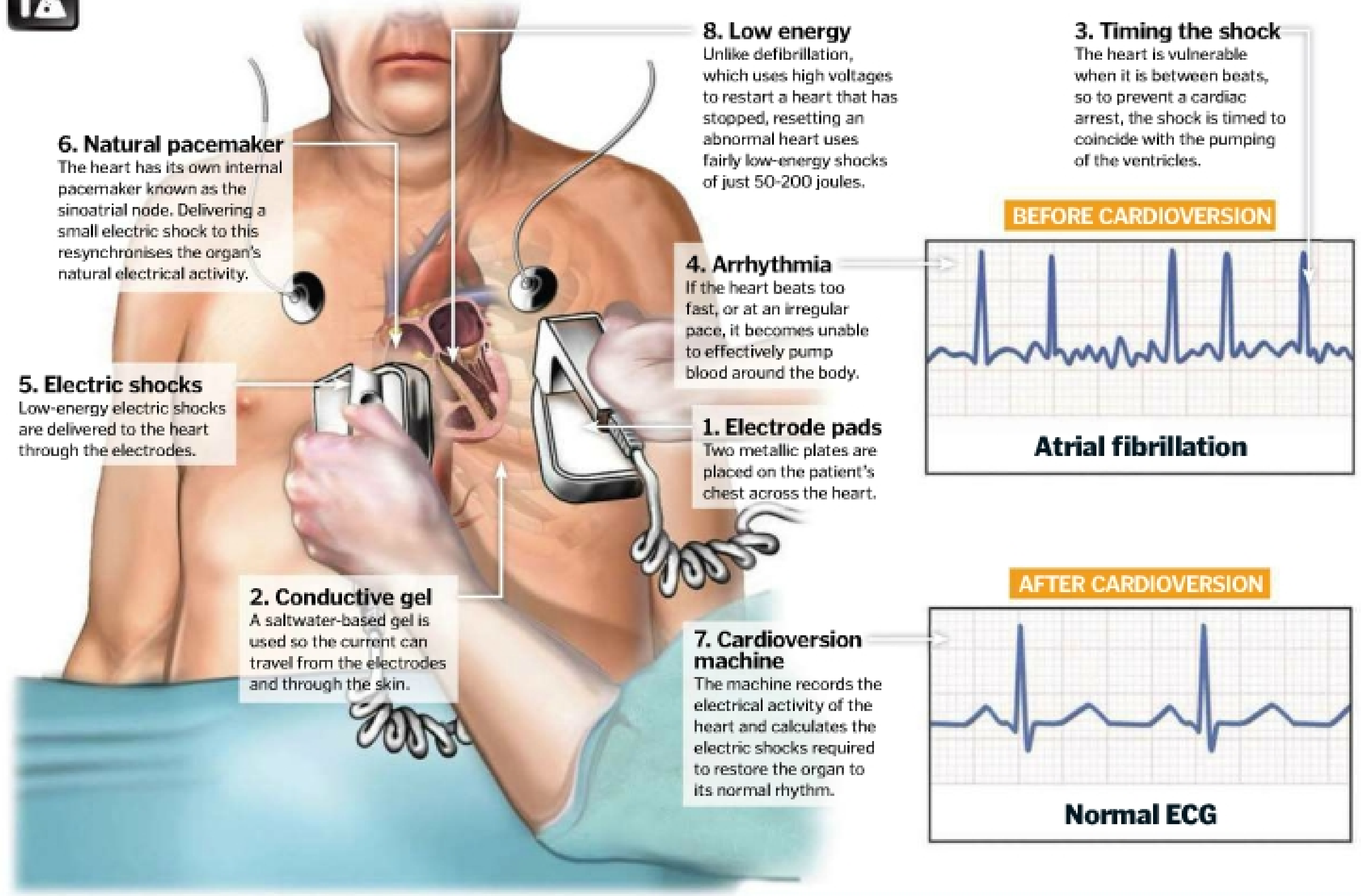
A geological stroke of luck allows Iceland to produce over 80 per cent of its energy (and 100 per cent of its electricity) from renewable sources. Straddling the Mid-Atlantic Ridge, a hub of tectonic plate activity, Iceland is dotted with over 200 volcanoes and some 600 hot springs, many of which spew out water at scalding temperatures of 250 degrees Celsius (482 degrees Fahrenheit). Exploiting this heat, geothermal energy meets 60 per cent of the country's energy needs. The hot water is used to warm houses, swimming pools and greenhouses directly, while geothermal plants also convert heat into electricity. Hydropower – made possible by the country's abundant rivers and waterfalls – makes up for a further 25 per cent of Iceland's energy requirement. This leaves 15 per cent of non-renewable energy, mostly used by oil-guzzling transport.

© Corbis; Thinkstock; Alamy; NASA

> *"The electric fields build up and electrons hurtle from the adhesive towards the tape"*

Correcting heart rhythms

How can a little electricity be used to fix a heart that's beating off-kilter?



8. Low energy
Unlike defibrillation, which uses high voltages to restart a heart that has stopped, resetting an abnormal heart uses fairly low-energy shocks of just 50-200 joules.

3. Timing the shock
The heart is vulnerable when it is between beats, so to prevent a cardiac arrest, the shock is timed to coincide with the pumping of the ventricles.

6. Natural pacemaker
The heart has its own internal pacemaker known as the sinoatrial node. Delivering a small electric shock to this resynchronises the organ's natural electrical activity.

4. Arrhythmia
If the heart beats too fast, or at an irregular pace, it becomes unable to effectively pump blood around the body.

5. Electric shocks
Low-energy electric shocks are delivered to the heart through the electrodes.

1. Electrode pads
Two metallic plates are placed on the patient's chest across the heart.

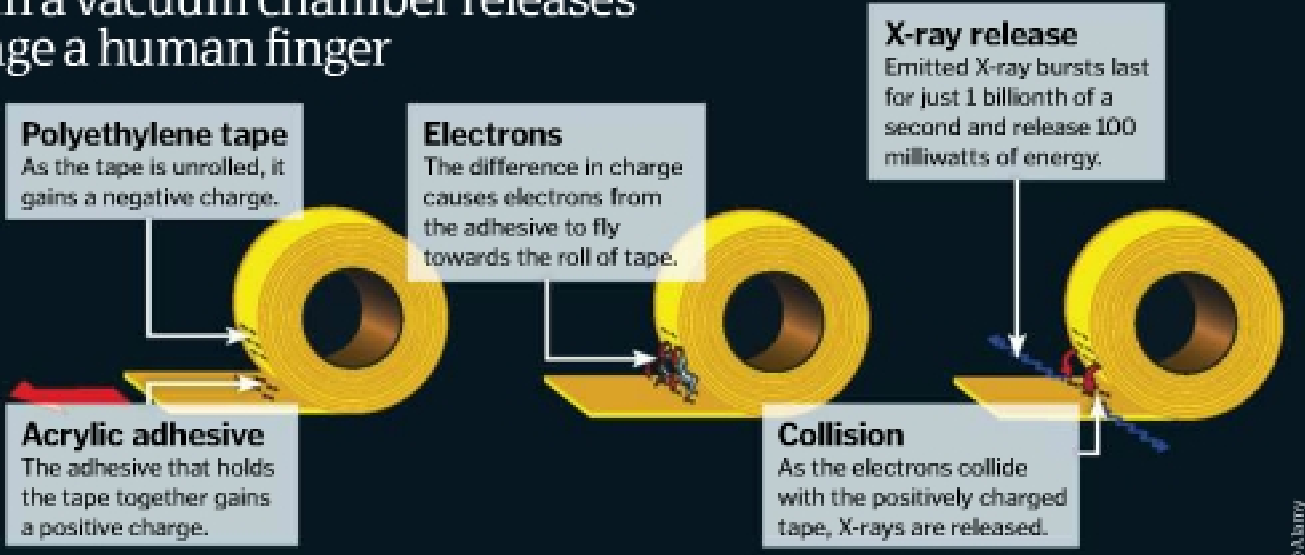
2. Conductive gel
A saltwater-based gel is used so the current can travel from the electrodes and through the skin.

7. Cardioversion machine
The machine records the electrical activity of the heart and calculates the electric shocks required to restore the organ to its normal rhythm.

X-ray tape unravelled

Peeling sticky tape off the roll in a vacuum chamber releases X-rays powerful enough to image a human finger

Occasionally when two surfaces move against one another, an electrical charge is generated and electromagnetic radiation – in the form of light, or X-rays – is released. This phenomenon is known as triboluminescence. As sticky tape is peeled from the roll, the acrylic adhesive becomes slightly positively charged, while the polyethylene tape becomes slightly negatively charged. The electric fields build up and electrons hurtle from the adhesive towards the tape, releasing X-rays on impact. ✽



Polyethylene tape
As the tape is unrolled, it gains a negative charge.

Acrylic adhesive
The adhesive that holds the tape together gains a positive charge.

Electrons
The difference in charge causes electrons from the adhesive to fly towards the roll of tape.

X-ray release
Emitted X-ray bursts last for just 1 billionth of a second and release 100 milliwatts of energy.

Collision
As the electrons collide with the positively charged tape, X-rays are released.

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BRAVEN BRV-1
- IPX-5 water-resistant; shockproof
- 12hr battery can also charge phones
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"the BRV-1 is a class-redefining product that is not only the Swiss Army Knife of portable speakers, but also the Chieftain tank".

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AWARD-WINNING PORTABLE SPEAKERS

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T3 TEST WINNER
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650
- Superior-quality apt-x Bluetooth audio
- 20hr battery life can also charge phones
- Bluetooth music and hands-free calls

625S
- Rugged casing, dry bag and LED torch
- 16hr battery life can also charge phones
- Bluetooth music and hands-free calls

600
- Stylish red or dark grey aluminium
- 12hr battery life can also charge phones
- Bluetooth music and hands-free calls

570
- White hot bargain Braven
- 10hr battery life can also charge phones
- Bluetooth music and hands-free calls

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> "They make mistakes and mutate often, developing new genes as they adapt to their environment"

RECORD BREAKERS
TINY GIANT

0.75mm

MOST MASSIVE BACTERIUM

Thiomargarita namibiensis can grow to nearly a millimetre in length and is visible to the naked eye. It contains granules of sulphur, which scatter light, giving it a pearlescent glow.

DID YOU KNOW? Some bacteria can transfer genetic material to one another, including antibiotic resistance genes

Micro world of bacteria

There's much more to these tiny organisms than food poisoning and superbugs

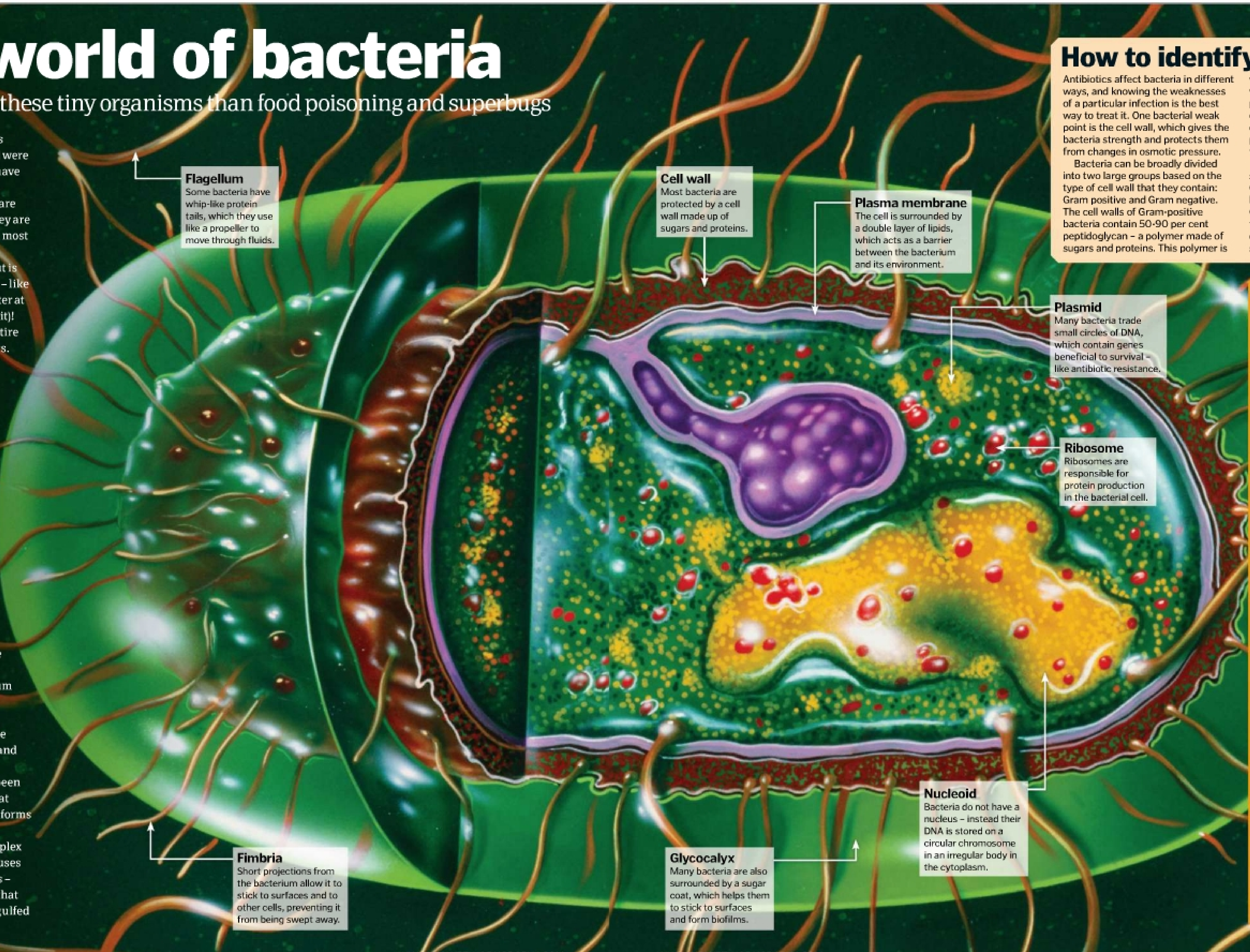
Bacteria are the most numerous living things on the planet, and were among the first forms of life to have evolved here, nearly 3.5 billion years ago.

These simple single-celled organisms are just fractions of a millimetre long, but they are incredibly adaptable and have colonised most environments. A single teaspoon of soil contains 1 billion bacteria, the human gut is colonised by 500-1,000 species and some – like Thermus aquaticus – can even live in water at 80 degrees Celsius (175 degrees Fahrenheit)!

Bacterial colonisation of almost the entire planet is a result of several characteristics. Firstly, they reproduce incredibly fast. Secondly, they are able to share genetic code by exchanging small fragments of DNA called plasmids – if one bacterium develops resistance to an antibiotic, it can share the genetic knowledge with its neighbours. Finally, bacteria have far fewer mechanisms to prevent errors being made in their DNA sequence, so they make mistakes and mutate often, developing new genes as they adapt to their environment.

Even though bacteria are single cells, they rarely live in isolation. They often attach to surfaces, and to one another, held together by a mucus-like carbohydrate matrix to form a biofilm. Within these bacterial colonies, individual cells make connections to one another to share nutrients. They also communicate with one another by quorum sensing; bacteria produce signalling molecules, which build up in the local environment, allowing them to detect the presence of other bacteria around them and change their behaviour accordingly.

Bacteria are not only thought to have been responsible for generating the oxygen that allowed the development of complex life forms on Earth, but scientists also believe that symbiotic bacteria gave rise to more complex organisms. Mitochondria – the powerhouses that generate energy inside our own cells – contain bacterial DNA, and it is thought that they originated as bacteria that were engulfed by their symbiotic companions. ✿



Flagellum
Some bacteria have whip-like protein tails, which they use like a propeller to move through fluids.

Cell wall
Most bacteria are protected by a cell wall made up of sugars and proteins.

Plasma membrane
The cell is surrounded by a double layer of lipids, which acts as a barrier between the bacterium and its environment.

Plasmid
Many bacteria trade small circles of DNA, which contain genes beneficial to survival – like antibiotic resistance.

Ribosome
Ribosomes are responsible for protein production in the bacterial cell.

Nucleoid
Bacteria do not have a nucleus – instead their DNA is stored on a circular chromosome in an irregular body in the cytoplasm.

Glycocalyx
Many bacteria are also surrounded by a sugar coat, which helps them to stick to surfaces and form biofilms.

Fimbria
Short projections from the bacterium allow it to stick to surfaces and to other cells, preventing it from being swept away.

How to identify bacteria

Antibiotics affect bacteria in different ways, and knowing the weaknesses of a particular infection is the best way to treat it. One bacterial weak point is the cell wall, which gives the bacteria strength and protects them from changes in osmotic pressure.

Bacteria can be broadly divided into two large groups based on the type of cell wall that they contain: Gram positive and Gram negative. The cell walls of Gram-positive bacteria contain 50-90 per cent peptidoglycan – a polymer made of sugars and proteins. This polymer is woven into a mesh many layers thick, which sits on the outside of the plasma membrane. In contrast, the cell walls of Gram-negative bacteria contain less than ten per cent peptidoglycan, sandwiched between two plasma membranes.

The purple stain, Gentian Violet, sticks to the peptidoglycan in Gram-positive bacteria, but cannot bind to the sandwiched layer in Gram-negative bacteria. This allows the two cell wall types to be easily distinguished, and is often the first stage in bacterial identification.

What shape are they?

1 Spheres

Cocci are spherical bacteria. They can exist as individuals, in chains (like streptococcus), in groups that resemble berries (like staphylococcus), and even assembled into cubes of eight spheres.

2 Rods

Rod-shaped bacteria (bacilli) normally exist alone, but can combine to form chains and include well-known culprits like E coli and Salmonella. The rod shape is maintained by a tough cell wall.

3 Comma

The most famous of these curved rod-shaped bacteria are those that cause cholera (ie Vibrio cholerae). Each has a single flagellum at one end, enabling it to swim through water.

4 Corkscrew

Spirilla are the least common type of bacteria and have a regular corkscrew shape. They often have flagella at either end to help propel them through fluids.

© Alamy

"If the tracheal opening is going to be a permanent feature then a piece of cartilage may be removed"

Tracheotomy surgery

Discover the science and tech behind this life-saving procedure

If the upper airway becomes blocked, either by facial trauma, cancer or inflammation, an alternative route must be found for air to enter the lungs.

Planned tracheotomies are performed under general anaesthesia or sedation. The neck is extended backwards to allow the surgeon to easily identify the structures in the throat and to make an accurate incision (see diagram). First, a vertical cut is made in the skin, below the tracheal cartilage, and the underlying muscle and blood vessels are carefully moved out of the way to expose the trachea.

The trachea is normally held open by C-shaped rings of cartilage, which prevent the airway from collapsing. A hole is made between the third and fourth rings, allowing the surgeon access to the airway without disrupting the cartilage supports. A tracheotomy tube is then inserted into the airway and secured to the neck. If the tracheal opening is going to be a permanent feature rather than temporary then a piece of cartilage may be removed to allow the tube to sit more comfortably.

The vocal cords sit just behind the tracheal cartilage, above the tracheotomy incision site, but in order to talk, air must be able to pass through the vocal cords to make them vibrate. Some tracheotomy tubes contain unidirectional valves, enabling the patient to breathe in through the tube and out through their mouth, which provides good air supply to the lungs, without hampering speech.

If the patient is unable to breathe unaided, a ventilator may be attached to mechanically move air in and out of the lungs.

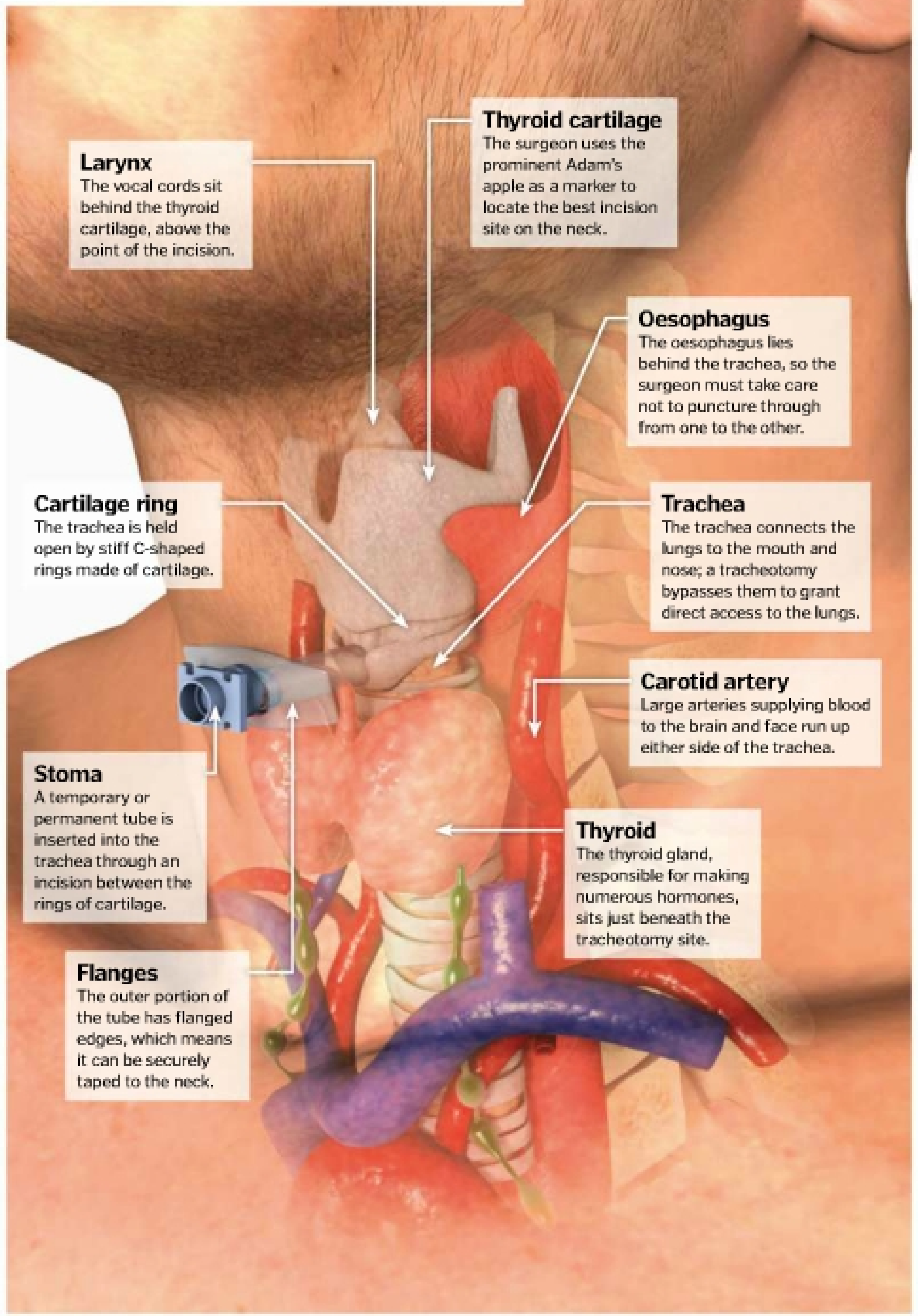
Have you got a pen?

A tracheotomy is a complex procedure, so in life-threatening, emergency situations a faster procedure – known as a cricothyrotomy (also called cricothyroidotomy) – may be performed. A higher incision is made just below the thyroid cartilage (Adam's apple) and then through the cricothyroid membrane, directly into the trachea.

It is possible to perform this procedure with a sharp instrument and any hollow tube, such as a straw or a ballpoint pen case. However, finding the correct location to make the incision is challenging, and without medical training there is great risk of damaging major blood vessels, the oesophagus or the vocal cords.

Anatomy of a tracheotomy

The trachea is surrounded by a minefield of major blood vessels, nerves, glands and muscles



Larynx
The vocal cords sit behind the thyroid cartilage, above the point of the incision.

Thyroid cartilage
The surgeon uses the prominent Adam's apple as a marker to locate the best incision site on the neck.

Oesophagus
The oesophagus lies behind the trachea, so the surgeon must take care not to puncture through from one to the other.

Cartilage ring
The trachea is held open by stiff C-shaped rings made of cartilage.

Trachea
The trachea connects the lungs to the mouth and nose; a tracheotomy bypasses them to grant direct access to the lungs.

Carotid artery
Large arteries supplying blood to the brain and face run up either side of the trachea.

Stoma
A temporary or permanent tube is inserted into the trachea through an incision between the rings of cartilage.

Thyroid
The thyroid gland, responsible for making numerous hormones, sits just beneath the tracheotomy site.

Flanges
The outer portion of the tube has flanged edges, which means it can be securely taped to the neck.

© Corbis

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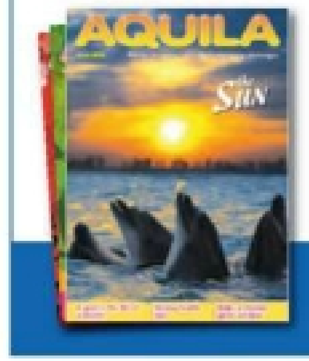

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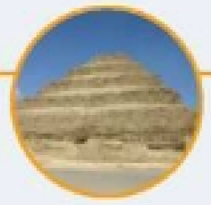
> "The radiocarbon dating process is a dependable method of measuring the age of organic remains"

KEY DATES
CARBON DATING

1946
Willard Libby publishes a paper proposing that the carbon in living matter may contain carbon-14.

1947
Libby and collaborators prove his theory correct with their findings published in *Science*.

1949
Libby and scientist James Arnold date pieces of Ancient Egyptian wood dating to 2800 BCE.



1960
Libby is awarded the Nobel Prize in Chemistry for his development of radiocarbon dating.

1977
An accelerator mass spectrometer is used for the first time to measure carbon-14 in samples smaller than a milligram.

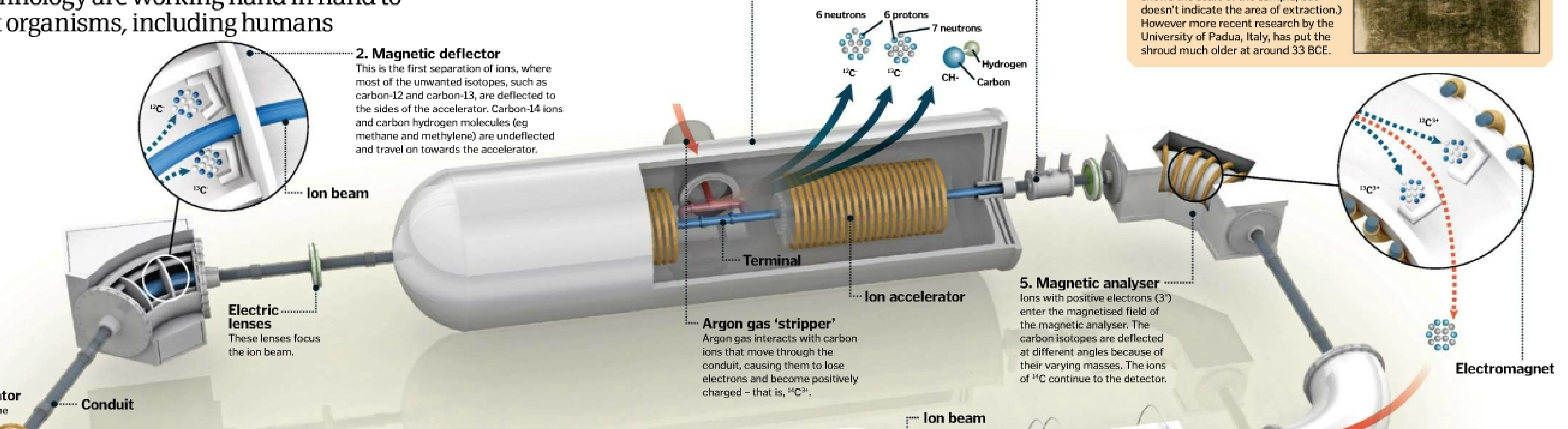
DID YOU KNOW? Carbon has two non-radioactive isotopes [carbon-12/13] and one radioactive isotope [carbon-14]

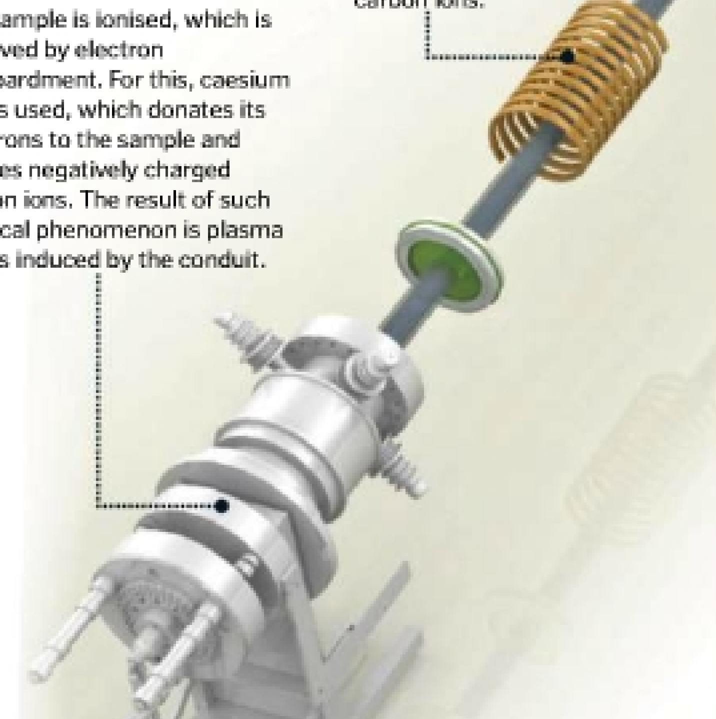
How is carbon dating used to age remains?

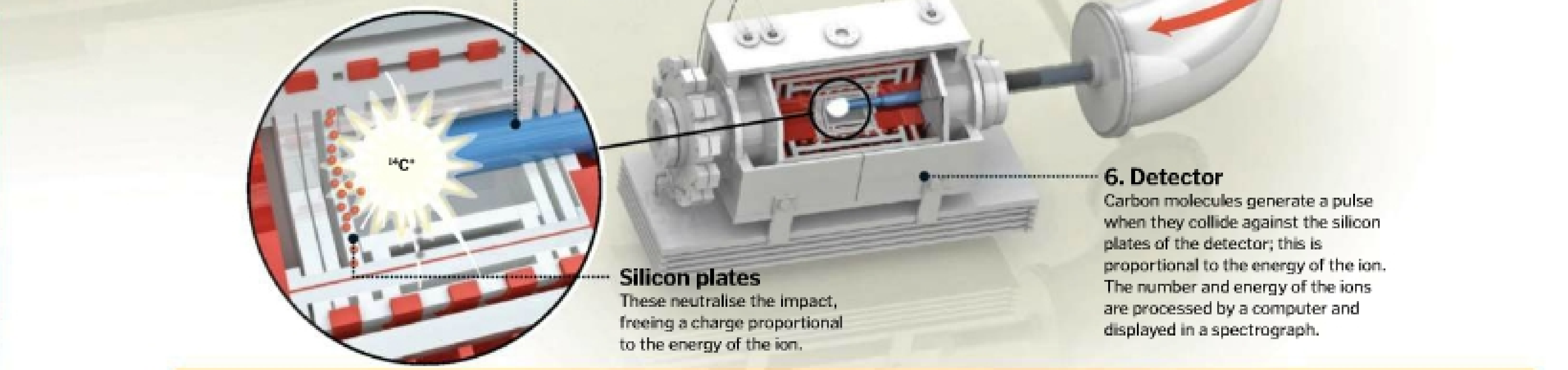
Learn how science and technology are working hand in hand to pinpoint the age of ancient organisms, including humans

Carbon dating is an ageing process that works by studying the decay of nitrogen in radiocarbon (carbon-14), with this substance present in every organic being. Carbon-14 is an intrinsic part of the biological carbon cycle on Earth, entering via green plants from the atmosphere and then passing up the food chain via animals. As such, while an organism is alive it will have a consistent level of carbon-14 stored in its cells.

Once an organism dies, however, that level of carbon-14 begins to decrease – something that occurs very slowly as carbon-14 has a half-life of 5,730 years, give or take 40 years. As a result, by measuring the radiocarbon, we can determine when the lifeform died (ie when the level of carbon-14 in its tissue stopped being topped up), though only to around 60,000 years ago.







1. Ionisation
The sample is ionised, which is achieved by electron bombardment. For this, caesium (Cs) is used, which donates its electrons to the sample and creates negatively charged carbon ions. The result of such physical phenomenon is plasma that is induced by the conduit.

Ion preaccelerator
This helps to direct the carbon ions.

Electric lenses
These lenses focus the ion beam.

2. Magnetic deflector
This is the first separation of ions, where most of the unwanted isotopes, such as carbon-12 and carbon-13, are deflected to the sides of the accelerator. Carbon-14 ions and carbon hydrogen molecules (eg methane and methylene) are undeflected and travel on towards the accelerator.

3. Accelerator
This generates a high voltage, forcing the negatively charged carbon ions to accelerate towards the positive terminal, where electrons are removed by a gas 'stripper'. These positive ions are then repelled by the positive terminal, accelerating towards the electrostatic deflector.

Argon gas 'stripper'
Argon gas interacts with carbon ions that move through the conduit, causing them to lose electrons and become positively charged – that is, $^{14}C^{3+}$.

4. Electrostatic deflector
This device creates an electrostatic field that deflects ions with a lower positive charge. Carbon atoms with higher positive charge, meanwhile, continue through the conduit.

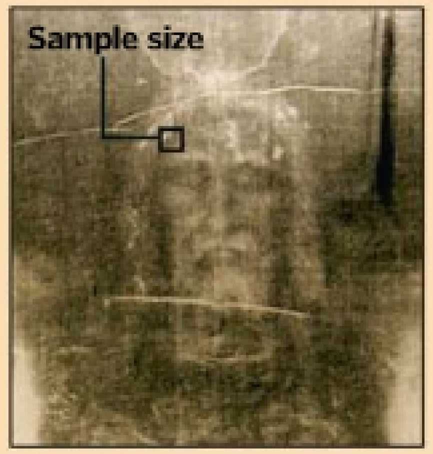
5. Magnetic analyser
Ions with positive electrons (3^+) enter the magnetised field of the magnetic analyser. The carbon isotopes are deflected at different angles because of their varying masses. The ions of ^{14}C continue to the detector.

6. Detector
Carbon molecules generate a pulse when they collide against the silicon plates of the detector; this is proportional to the energy of the ion. The number and energy of the ions are processed by a computer and displayed in a spectrograph.

Silicon plates
These neutralise the impact, freeing a charge proportional to the energy of the ion.

The Turin Shroud

Three universities were chosen to date the ancient linen Turin Shroud in 1988, believed by some to have covered Jesus after he was crucified, but carbon dating concluded it was a medieval forgery. The sample consisted of a seven-centimetre (2.8-inch) cut, divided into three parts. (This image shows the scale of the sample, but doesn't indicate the area of extraction.) However more recent research by the University of Padua, Italy, has put the shroud much older at around 33 BCE.



Carbon dating can be used to date human bones both from ancient times and the modern era

Five alternative methods used to date artefacts

1. Dendrochronology
The technical name for dating tree rings. Every tree produces a ring per year, with the thickness varying according to climatic conditions. This method is very accurate, but is only useful for ageing up to 10,000 years back.

2. Rehydroxylation
Commonly used to date ceramic wares, this technique enables us to measure the amount of water that the clay elements have reabsorbed since they were fired to reveal fairly accurately when they were made.

3. Potassium-argon
Like carbon-14, it is based on radioactive decay, but in the potassium-40 isotope. It can date rocks that are billions of years old, but due to the long half-life of potassium-40, it's not generally used for samples under 100,000 years old.

4. Uranium-238
This form of radioactive dating depends on the decay of uranium-238. Materials that are billions of years old can be dated with this technique, offering the chance for speculation about the very origins of Earth.

5. Thermoluminescence
This method measures the radiation emitted by the crystalline structure of inorganic matter, like pottery, in a time range similar to that of carbon-14. One of the main drawbacks of thermoluminescence is its high error margin.

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HEAVIEST-EVER BATTLESHIP

When fully laden the Yamato-class battleship, which was used by Japan during World War II, weighed in at 73,000 tons – making it by far the heaviest warship ever constructed.

DID YOU KNOW? A Zumwalt-class destroyer costs around £2.4bn ($3.8bn) to build

The British Type 45 has a displacement of 8,000 tons and can carry a crew of around 190

NEXT-GEN BATTLESHIPS

The firepower on the latest battleships is mind-boggling – we explore the technology transforming 21st-century naval warfare

If you thought that the golden age of naval combat came to an end 200 years ago, then clearly somebody forgot to tell the national navies of today, as a wave of state-of-the-art, armed-to-the-teeth battleships are currently emerging from shipbuilding yards with a singular aim in mind: total domination of the seas.

From the brand-new and brutal Type 45 destroyers being pushed out of British dockyards, through to the almost sci-fi Zumwalt-class battleships emerging in the USA, and on to the cruising carrier vessels sitting like small islands in Earth's oceans, battleships are being produced en masse and to a more advanced spec than ever before.

Far from the basic heavyweights of bygone centuries, required simply to go toe-to-toe with each other in a deadly game of broadsides, today's warships need to take down a variety of threats, whether at sea, on land or in the air, and they need to do so at extreme range. As such, step onto a battleship today – be it a frigate, destroyer or corvette – and you'll find an arsenal of insane weapons systems.

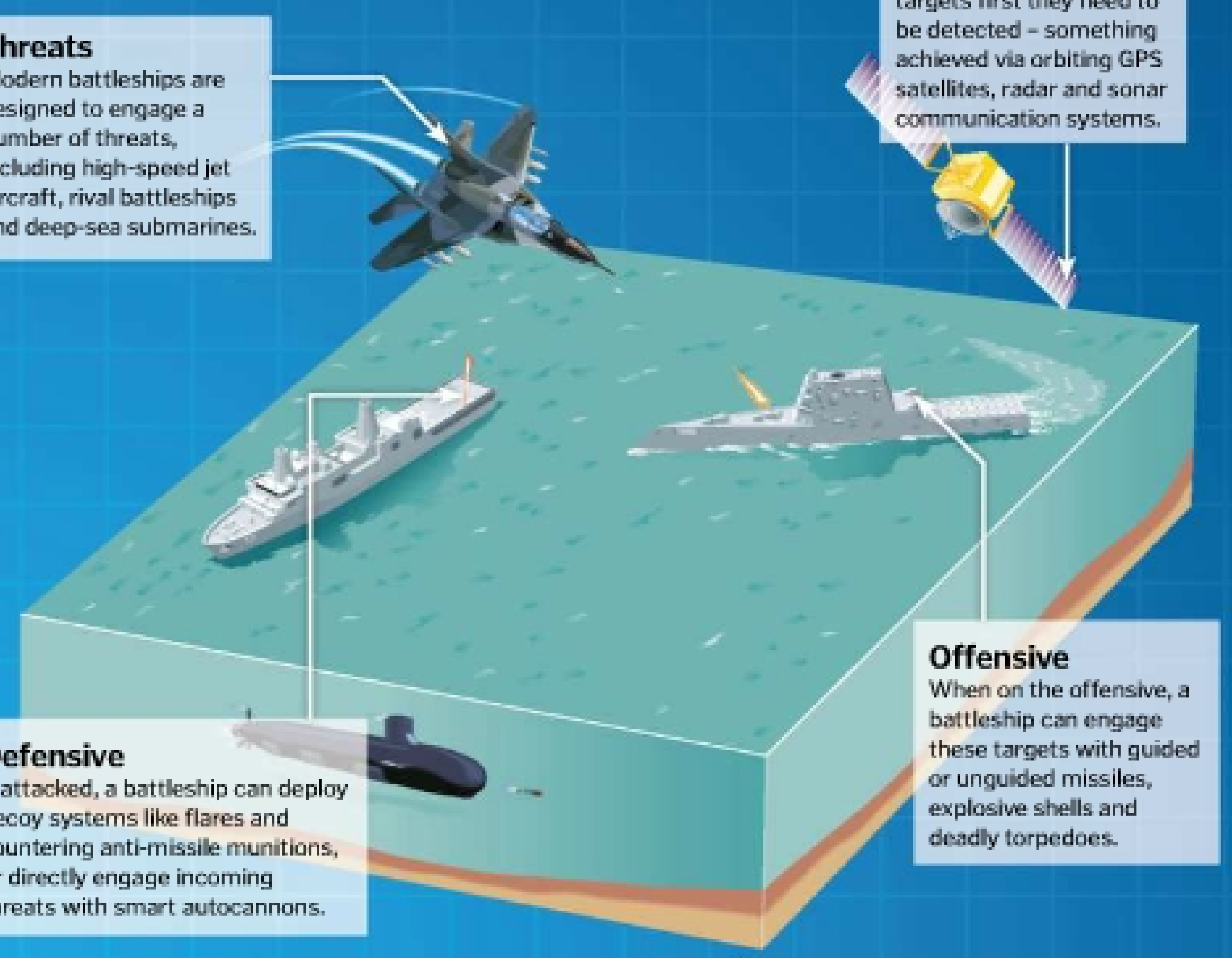
There are cannons that can fire over distances of 95 kilometres (60 miles) and deliver a guided smart munition to a target with pinpoint accuracy, as well as Gatling guns that can automatically track a target moving at hundreds of miles per hour and then fire explosive bullets at up to 1,100 metres (3,610 feet) per second to take it down.

Missile launch systems not only increase the vessel's stealth but are capable of launching a wide variety of city block-levelling missiles directly into the heart of enemy encampments in minutes from a safe distance, while naval guns are capable of subjecting a target to continuous bombardment with high-explosive shells with controlled abandon. All this is but a taste of the weaponry being fitted to the most advanced 21st-century warships.

The heavy armament of vessels currently knows no bounds, with even coastguard fleets, convoy vehicles and civilian support ships being outfitted with some form of military-grade offensive weaponry. Clearly, controlling the world's waters is not as old-fashioned as the history books would have us believe. In this feature we take a look at the various types of battleship taking to the seas and the weapon systems that are revolutionising not just naval combat but warfare in general. ✿

Rules of engagement

The key stages and technology that decide the outcome of a modern naval battle



Threats
Modern battleships are designed to engage a number of threats, including high-speed jet aircraft, rival battleships and deep-sea submarines.

Detection
To engage any of these targets first they need to be detected – something achieved via orbiting GPS satellites, radar and sonar communication systems.

Offensive
When on the offensive, a battleship can engage these targets with guided or unguided missiles, explosive shells and deadly torpedoes.

Defensive
If attacked, a battleship can deploy decoy systems like flares and countering anti-missile munitions, or directly engage incoming threats with smart autocannons.

A high-explosive guided torpedo is projected from a US battleship

More traditional 41cm (16in) naval guns on board the USS North Carolina

USS Iowa unloads a volley of explosive shells from its Mark 7 naval guns

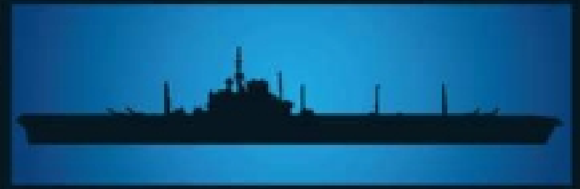
Battleship types

1 Corvette
One of the smallest types, the corvette is a lightly armed and manoeuvrable vessel used for coastal operations. Stealth corvettes are now becoming popular too.

2 Frigate
Lightly armed, medium-sized ships generally used to protect other military or civilian vessels. Recently, frigates have been re-focused to take out submarines.

3 Destroyer
Large and heavily armed, destroyers are typically outfitted for anti-submarine, anti-aircraft and anti-surface warfare, and can remain at sea for months on end.

4 Cruiser
The cruiser is an armed-to-the-teeth multi-role vessel akin to a modern destroyer. While cruisers are still in use, they have largely been superseded now.



5 Carrier
Ocean-going leviathans, carriers are the largest battleship. Their primary role is as a seagoing airbase, launching combat aircraft, but they also come heavily armed.

> "The Advanced Gun System can fire ten of these LRLAPs per minute from its stealth-designed turret"

AMAZING VIDEO! SCAN THE QR CODE FOR A QUICK LINK
Watch 16-inch battleship cannons fired at sea!

U KNOW? The Type 26 frigate is installed with the Phalanx close-in weapon system

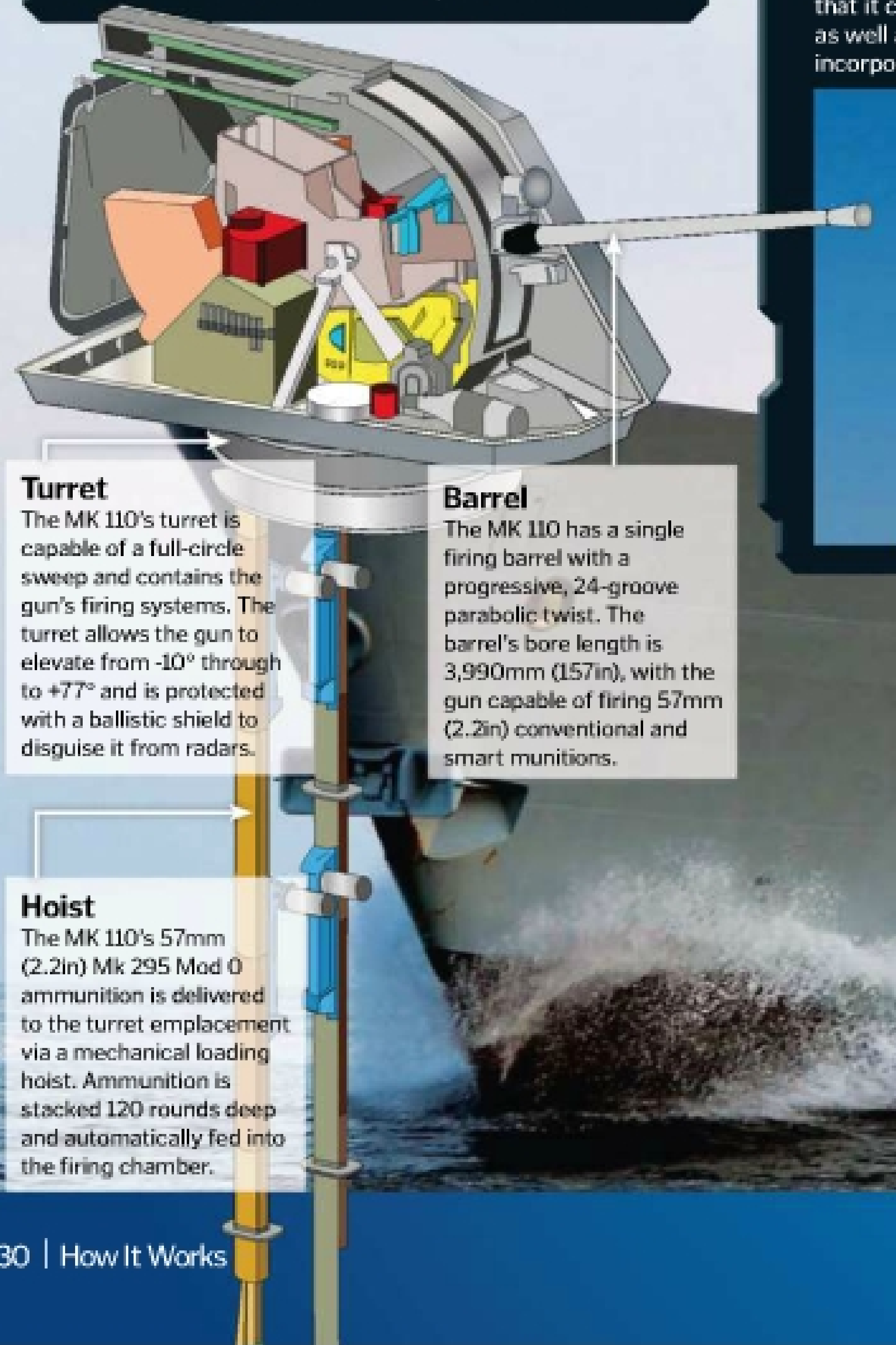
Weapons in focus

We train our sights on four of the most advanced armaments aboard the latest battleships

Mk 110 naval gun

FIRE POWER 3 FIRE POWER

Capable of delivering automatic salvos of 220 57-millimetre (2.2-inch) Mk 295 Mod 0 ammunition – read: fragmenting high-explosive shells – each and every minute, the Mk 110 naval gun is quite simply a shell-slinging colossus. Stemming from one of the most long-lasting naval gun series of the last 100 years, the Mk 110 comes with a selection of hot features. These include the ability to fire both standard and smart munitions, a gun barrel-mounted radar for refined measuring of muzzle velocity, an instantaneous ability to switch between ammunition types, a stealth-oriented ballistic shield that protects the gun while allowing a full 360-degree traverse, plus a fully digital fire control system that enables the Mk 110 to respond to exact pointing orders and ammunition fuse selection milliseconds prior to firing. Indeed, the only thing that stops the Mk 110 from bombarding its target continuously is its shell capacity, which rests at 120 rounds with a three-minute reload process.



Turret
The MK 110's turret is capable of a full-circle sweep and contains the gun's firing systems. The turret allows the gun to elevate from -10° through to +77° and is protected with a ballistic shield to disguise it from radars.

Barrel
The MK 110 has a single firing barrel with a progressive, 24-groove parabolic twist. The barrel's bore length is 3,990mm (157in), with the gun capable of firing 57mm (2.2in) conventional and smart munitions.

Hoist
The MK 110's 57mm (2.2in) Mk 295 Mod 0 ammunition is delivered to the turret emplacement via a mechanical loading hoist. Ammunition is stacked 120 rounds deep and automatically fed into the firing chamber.

Advanced Gun System

FIRE POWER 4 FIRE POWER

The Advanced Gun System (AGS) is a new naval gun from BAE Systems capable of firing precision munitions super-fast and at over-the-horizon ranges. What makes it special is that far from firing traditional unguided shells – as most naval guns have been designed for – it fires the Long Range Land Attack Projectile (LRLAP), a 155-millimetre (6.1-inch) precision guided artillery shell that, thanks to base bleed rocket assistance and an extended range fin glide trajectory, can travel over 105 kilometres (65 miles) to a target. What's more, it then has a circular error probable (ie accuracy) of only 50 metres (164 feet), making it incredibly precise even at great distance. Throw in the fact that the AGS can fire ten of these LRLAPs per minute from its stealth-designed turret and that it can fire traditional unguided munitions as well and it becomes clear why it's being incorporated into many of today's warships.

Vertical Launch System

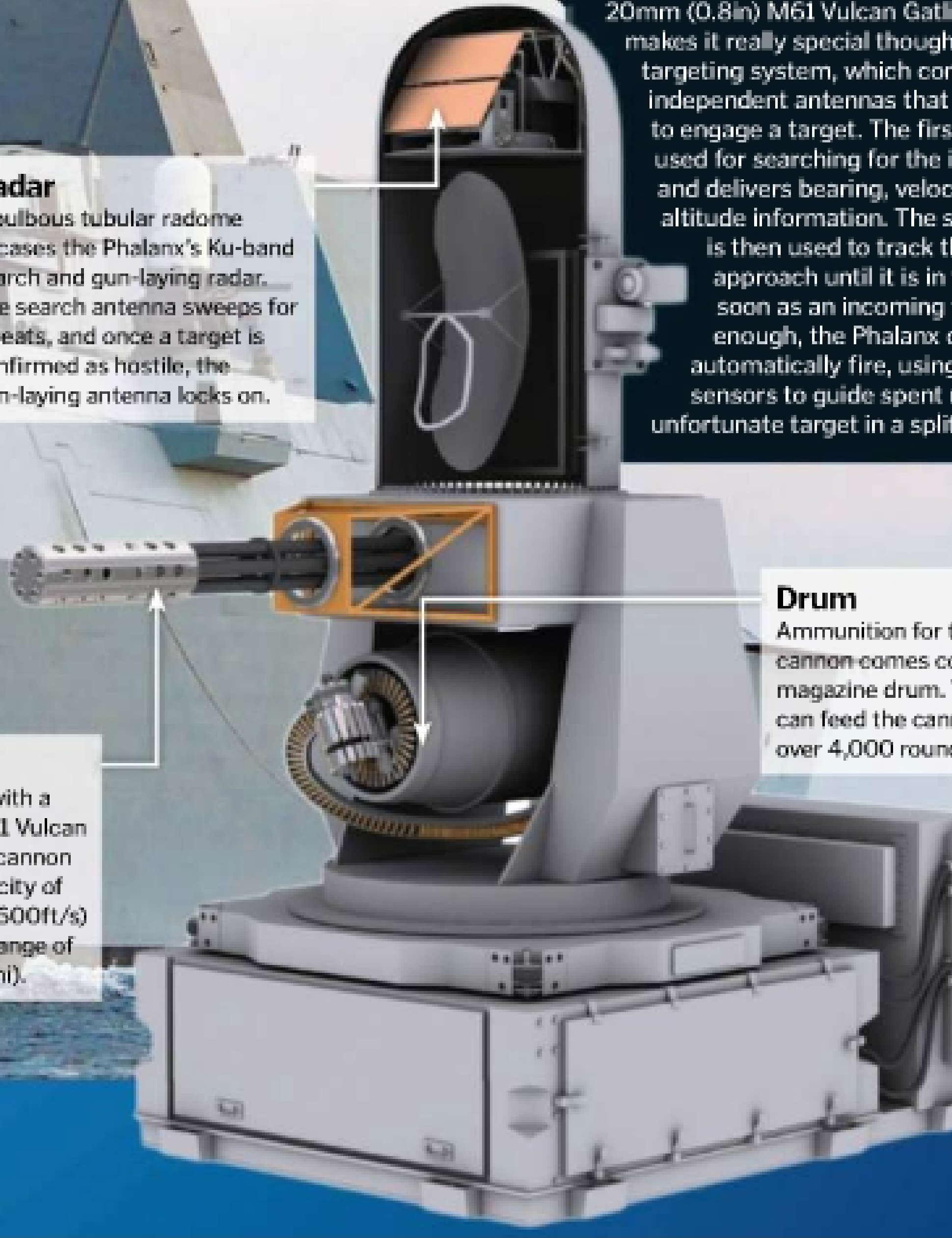
FIRE POWER 5 FIRE POWER

The Vertical Launch System (VLS) is a state-of-the-art multi-missile launching system. Unlike previous systems, which could only fire one specific type of missile, the VLS is modular so a variety of projectiles can be fired from the same enclosures. The missiles, which on the Zumwalt-class destroyers include the RIM-162 Evolved Seasparrow missile, Anti-Submarine Rocket (ASROC) and Tactical Tomahawk subsonic cruise missile, are enclosed in a series of launch cells within the ship's hull and, when launched, are fired out of the top of the deck. By concealing the missiles within the ship until needed, the VLS improves the ship's overall radar cross-section, making it harder to detect. Each missile fired from a VLS cell is of the guided variety, with a selection of high-explosive warheads directed to the target by radar or GPS.

Phalanx CIWS

FIRE POWER 3 FIRE POWER

Every battleship built today comes with a close-in weapon system, or CIWS, and out of these systems the Phalanx CIWS is the leader of the pack. It is a point-defence weapon designed to attack any target – be that enemy fighter jets or missiles – which has managed to evade the battleship's longer-range offensive weapons with its massive 20mm (0.8in) M61 Vulcan Gatling gun. What makes it really special though is its advanced targeting system, which consists of two independent antennas that work together to engage a target. The first antenna is used for searching for the incoming target and delivers bearing, velocity, range and altitude information. The second antenna is then used to track the target on its approach until it is in firing range. As soon as an incoming target is close enough, the Phalanx can then automatically fire, using a selection of sensors to guide spent rounds at the unfortunate target in a split second.



Radar
A bulbous tubular radome encases the Phalanx's Ku-band search and gun-laying radar. The search antenna sweeps for threats, and once a target is confirmed as hostile, the gun-laying antenna locks on.

Gun
Damage is dealt with a 20mm (0.8in) M61 Vulcan autocannon. The cannon has a muzzle velocity of over 1,100m/s (3,600ft/s) and an effective range of up to 3.6km (2.2mi).

Drum
Ammunition for the Gatling cannon comes courtesy of a large magazine drum. This dispenser can feed the cannon at a rate of over 4,000 rounds per minute.

© Ian Moores Graphics; Corbis; Getty; BAE Systems

> "A typical car today can run for approximately 480 kilometres (300 miles) on one tank of fuel"

5 TOP FACTS

FUEL YOUR MIND

Plane mad

1 Using much bigger engines, a Boeing 747 can burn through about four litres (a gallon) of fuel a second. On a ten-hour flight it might use up to 150,000 litres (36,000 gallons)!

Rise of biofuels

2 All diesel and petrol for road-going vehicles now contain some biofuel – up to five per cent ethanol in petrol and up to seven per cent biodiesel in diesel.

Dominant diesel

3 Although petrol generally used to be the fuel of choice, more and more drivers are buying diesel cars because they achieve more miles per gallon (MPG) for the most part.

Keeping cool costs

4 Using air conditioning increases your fuel consumption as it's making your engine work harder. To make fuel go further, turn off all in-car gimmicks.

Premium price

5 Due to a growing shortage of crude oil from which petrol is derived, global prices of fuel have rocketed by nearly 70 per cent in the last six years, and only seem to be rising.

DID YOU KNOW? *Over 30 billion litres (7.9 billion gallons) of fuel are sold on UK forecourts each year*

Car fuel systems

Fuel is a vital component in getting a vehicle to move, but what happens after you've filled up your tank?

For decades now, vehicles have been powered by combustion engines that rely on a constant feed of both air and fuel combining together to essentially explode.

As with a normal fire, oxygen is the catalyst for any explosion or ignition. The principle is the same inside a car's engine, where oxygen is mixed with fuel while simultaneously being fed into the cylinder heads where these controlled explosions force a series of pistons down, turning the crankshaft and helping to propel the vehicle along the road. Without these vital ingredients, the engine simply couldn't work.

When you fill up, fuel (either petrol or diesel) flows along a fuel line and down into a tank. The fuel is stored here in excess, but gradually empties as a pump provides a constant feed to the engine as soon as the car is fired up.

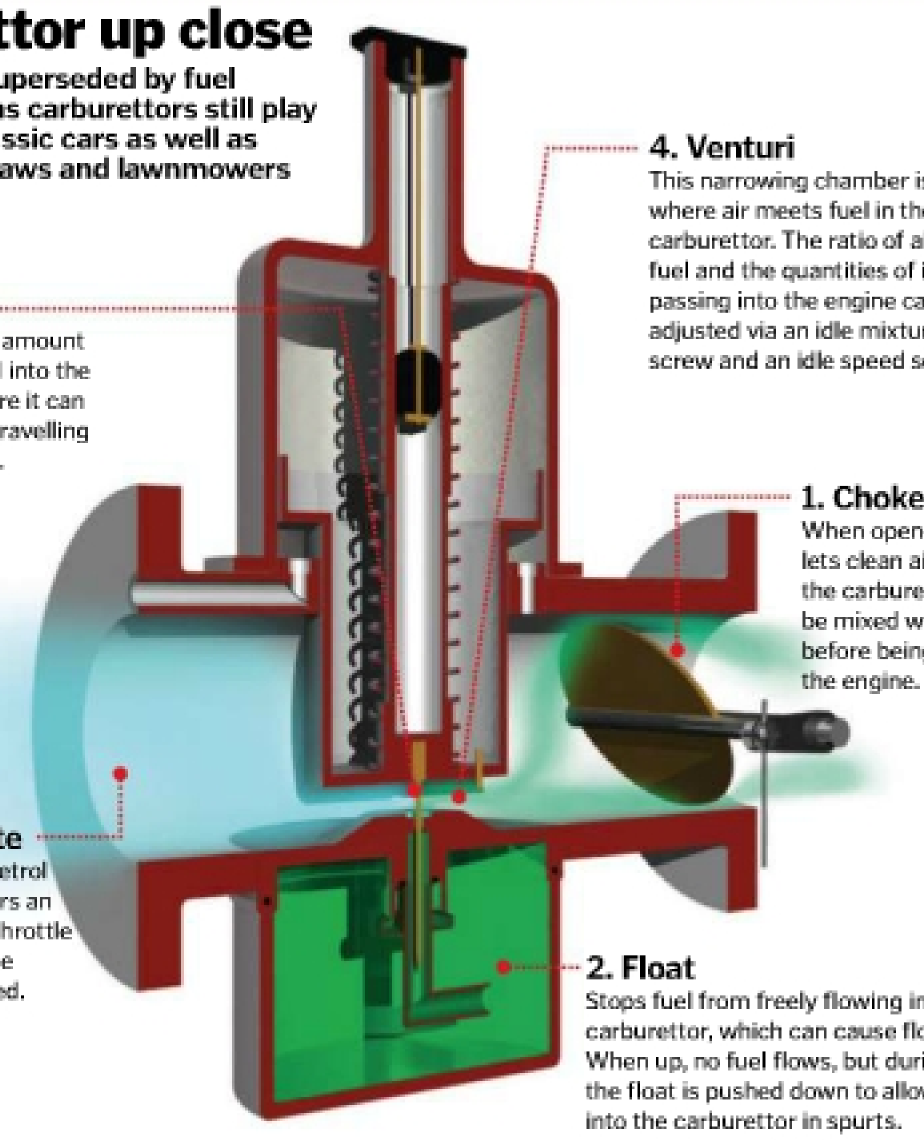
Once fuel leaves the tank, it is deposited via a rail into either a manifold on older systems, or – more likely today – straight into a cylinder head using direct fuel injection.

On older vehicles, a carburettor is used to adjust and measure the levels of air and fuel entering an engine, ensuring the right amount of both ingredients is supplied so that the vehicle runs efficiently. The job of carburettors is now also performed by fuel injectors in tandem with an engine control unit (ECU).

Fuel is burned in the engine, but some excess may be left over, which is simply taken back to the tank via a return line ready to be used again. A typical car today can run for approximately 480 kilometres (300 miles) on one tank of fuel – depending, of course, on conditions and the behaviour of the driver.

Carburettor up close

Although now superseded by fuel injection systems carburettors still play a vital role in classic cars as well as tools like chainsaws and lawnmowers



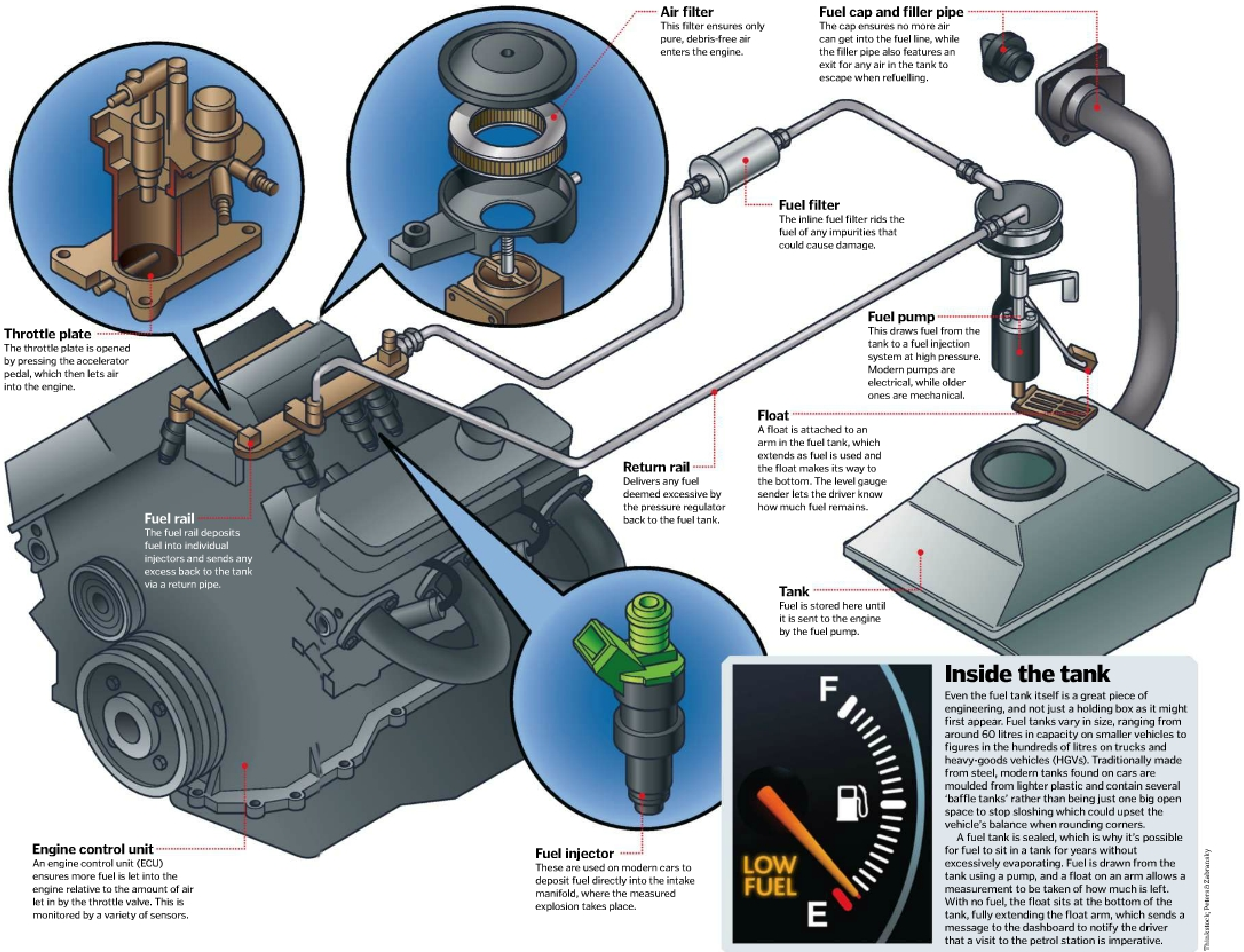
4. Venturi
This narrowing chamber is where air meets fuel in the carburettor. The ratio of air to fuel and the quantities of it passing into the engine can be adjusted via an idle mixture screw and an idle speed screw.

3. Jet
The jet allows a fine amount of fuel to be sprayed into the narrow venturi, where it can mix with air before travelling to the inlet manifold.

1. Choke plate
When opened, this lets clean air enter the carburettor to be mixed with fuel before being fed to the engine.

5. Throttle plate
Dictates when the petrol and air mixture enters an engine; in a car the throttle plate opens when the accelerator is pressed.

2. Float
Stops fuel from freely flowing into a carburettor, which can cause flooding. When up, no fuel flows, but during use the float is pushed down to allow fuel into the carburettor in spurts.



Throttle plate
The throttle plate is opened by pressing the accelerator pedal, which then lets air into the engine.

Air filter
This filter ensures only pure, debris-free air enters the engine.

Fuel cap and filler pipe
The cap ensures no more air can get into the fuel line, while the filler pipe also features an exit for any air in the tank to escape when refuelling.

Fuel filter
The inline fuel filter rids the fuel of any impurities that could cause damage.

Fuel pump
This draws fuel from the tank to a fuel injection system at high pressure. Modern pumps are electrical, while older ones are mechanical.

Float
A float is attached to an arm in the fuel tank, which extends as fuel is used and the float makes its way to the bottom. The level gauge sender lets the driver know how much fuel remains.

Return rail
Delivers any fuel deemed excessive by the pressure regulator back to the fuel tank.

Fuel rail
The fuel rail deposits fuel into individual injectors and sends any excess back to the tank via a return pipe.

Tank
Fuel is stored here until it is sent to the engine by the fuel pump.

Engine control unit
An engine control unit (ECU) ensures more fuel is let into the engine relative to the amount of air let in by the throttle valve. This is monitored by a variety of sensors.

Fuel injector
These are used on modern cars to deposit fuel directly into the intake manifold, where the measured explosion takes place.

Inside the tank

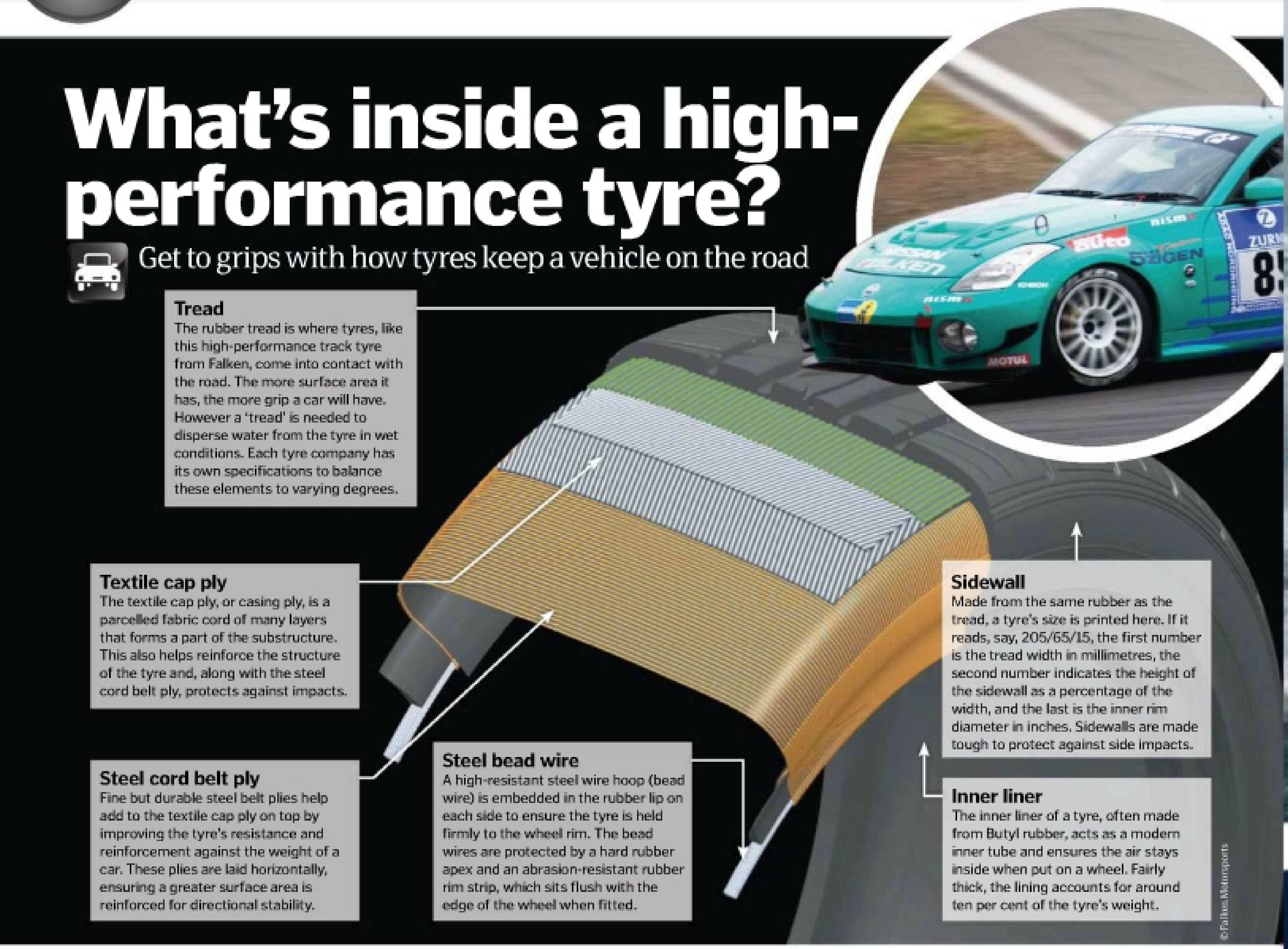
Even the fuel tank itself is a great piece of engineering, and not just a holding box as it might first appear. Fuel tanks vary in size, ranging from around 60 litres in capacity on smaller vehicles to figures in the hundreds of litres on trucks and heavy-goods vehicles (HGVs). Traditionally made from steel, modern tanks found on cars are moulded from lighter plastic and contain several 'baffle tanks' rather than being just one big open space to stop sloshing which could upset the vehicle's balance when rounding corners.

A fuel tank is sealed, which is why it's possible for fuel to sit in a tank for years without excessively evaporating. Fuel is drawn from the tank using a pump, and a float on an arm allows a measurement to be taken of how much is left. With no fuel, the float sits at the bottom of the tank, fully extending the float arm, which sends a message to the dashboard to notify the driver that a visit to the petrol station is imperative.

© Thinkstock; Peters & Zabransky

What's inside a high-performance tyre?

Get to grips with how tyres keep a vehicle on the road



Tread
The rubber tread is where tyres, like this high-performance track tyre from Falken, come into contact with the road. The more surface area it has, the more grip a car will have. However a 'tread' is needed to disperse water from the tyre in wet conditions. Each tyre company has its own specifications to balance these elements to varying degrees.

Textile cap ply
The textile cap ply, or casing ply, is a parcelled fabric cord of many layers that forms a part of the substructure. This also helps reinforce the structure of the tyre and, along with the steel cord belt ply, protects against impacts.

Steel cord belt ply
Fine but durable steel belt plies help add to the textile cap ply on top by improving the tyre's resistance and reinforcement against the weight of a car. These plies are laid horizontally, ensuring a greater surface area is reinforced for directional stability.

Steel bead wire
A high-resistant steel wire hoop (bead wire) is embedded in the rubber lip on each side to ensure the tyre is held firmly to the wheel rim. The bead wires are protected by a hard rubber apex and an abrasion-resistant rubber rim strip, which sits flush with the edge of the wheel when fitted.

Sidewall
Made from the same rubber as the tread, a tyre's size is printed here. If it reads, say, 205/65/15, the first number is the tread width in millimetres, the second number indicates the height of the sidewall as a percentage of the width, and the last is the inner rim diameter in inches. Sidewalls are made tough to protect against side impacts.

Inner liner
The inner liner of a tyre, often made from Butyl rubber, acts as a modern inner tube and ensures the air stays inside when put on a wheel. Fairly thick, the lining accounts for around ten per cent of the tyre's weight.

© Falken Motorsports

Watertight doors

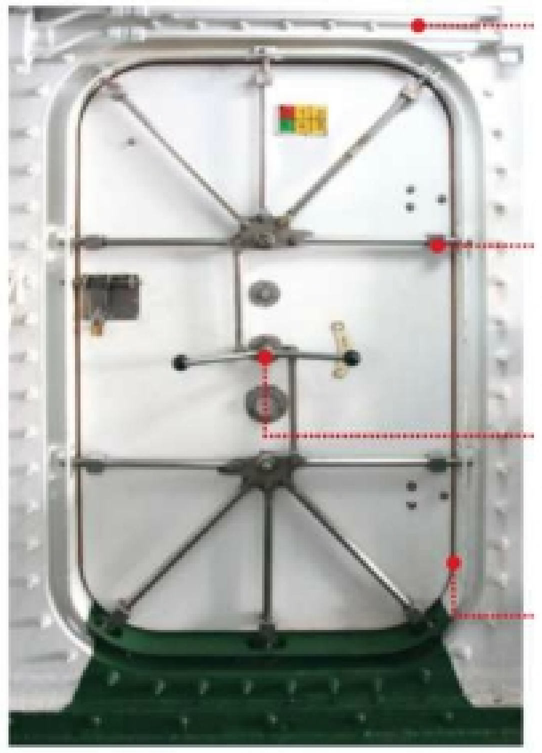
How do these special ship doors manage to hold their own against a flood of oncoming water?

Simple in design and yet vital in their role as an access solution in marine industries, watertight doors are able to stop water passing even under huge pressure.

Essential to their operation is a seal around the perimeter of the entrance being fully compressed and in contact with the 'knife edge' of the frame to prevent leakage. Equally, these doors must be incredibly strong and stiff (hence why they're usually made from steel) to prevent any form of deformation or warping from the heavy loads brought by a head of water. To aid this, a watertight door will also have strategically located locking points to provide sufficient compression of the seal all over. These locking points are traditionally activated via a single central wheel/bar found in the middle of the door for ease of use.

Watertight doors can either be hinged or sliding, square or radial, and they come in a number of different sizes.

> "A watertight door will have strategically located locking points to provide compression of the seal"



Structure
The frame must be reinforced to compensate for the weakening caused by the doorway.

Locking clip
Four, six or eight clips help 'lock' the door to the ship's structure and tighten the seal.

Locking bar
Quick-acting turning ensures the door is sealed via locking clips with minimal effort.

Seal
Usually rubber, this is depressed by the door to stop any liquid from leaking through.

5 TOP FACTS: TYPE 45 HMS DARING

The Launch
The first ship in the Daring-class, HMS Daring, was launched on 1 February 2006 and commissioned on 23 July 2009.

Size
The Type 45 Destroyers are much larger than the Type 42 they replaced. Being 152.4 m in length, with a beam of 21.2 m and a draught of 7.4 m.

Accommodation
The Type 45s are the first Royal Navy ships to include gender neutral living spaces.

Replacing Type 42 Destroyers
It is suggested that, during an "intensive attack", a single Type 45 could simultaneously track, engage and destroy more targets than five Type 42 Destroyers operating together.

Costly
The Type 45 is not cheap, costing over £1,050M per ship.

AIRFIX How it works

Either one AgustaWestland Merlin or two Lynx helicopters can be carried aboard.

Air defence is the ships primary role, with powerful radar assisting this task.

The ships primary conventional weapon is a BAE systems 4.5 inch mark 8.

Two Rolls-Royce WR-21 gas turbine alternators and two Wärtsilä 12V200 diesel generators provide electrical power at 4,160 volts to a high voltage system. The high voltage supply is then used to provide power to two Converteam advanced induction motors with outputs of 20 MW (27,000 hp) each.

For more information on the HMS Daring Type 45 Destroyer, please scan this QR Code with your smartphone.

There are 6 ships in the Type 45 class.

TYPE 45 HMS DARING

Britain's six Type 45 'Daring Class' Destroyers are the most advanced escorts the nation has ever built. They are designed to shield a naval task force from air attack by using the Sea Viper missile system. Their Aster missiles can knock targets out of the sky over 70 miles away if required. The Type 45 destroyers are also capable of a range of other roles and will spend their commissions switching between them, often at short notice.

A50132 1:350 Scale Type 45 HMS Daring

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> "Less than 25 of these bridges have ever been constructed – and only a few remain in use today"

RECORD BREAKERS
BRIDGING THE GAP

300m

BIGGEST TRANSPORTER BRIDGE

The Widnes-Runcorn Transporter Bridge over the River Mersey, UK, was the largest ever built. It had a main span of 300 metres (984 feet) and two towers each 58 metres (190 feet) high. However it was demolished in 1961.

DID YOU KNOW? *Only six transporter bridges remain in operation around the world, most of which are in Europe*

Aerial transfer bridges

Learn how transporter bridges carry cargo and passengers across water

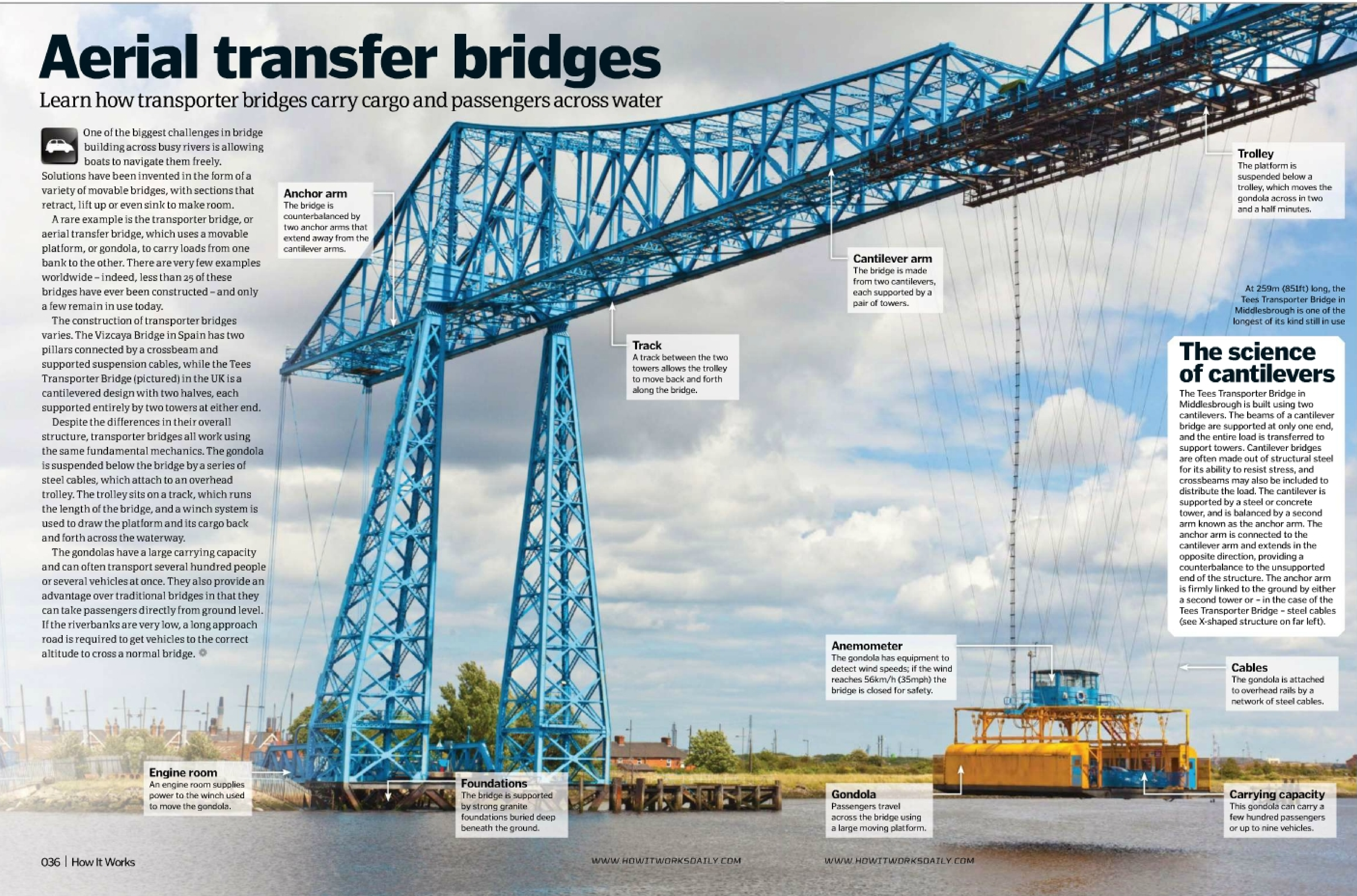
One of the biggest challenges in bridge building across busy rivers is allowing boats to navigate them freely. Solutions have been invented in the form of a variety of movable bridges, with sections that retract, lift up or even sink to make room.

A rare example is the transporter bridge, or aerial transfer bridge, which uses a movable platform, or gondola, to carry loads from one bank to the other. There are very few examples worldwide – indeed, less than 25 of these bridges have ever been constructed – and only a few remain in use today.

The construction of transporter bridges varies. The Vizcaya Bridge in Spain has two pillars connected by a crossbeam and supported suspension cables, while the Tees Transporter Bridge (pictured) in the UK is a cantilevered design with two halves, each supported entirely by two towers at either end.

Despite the differences in their overall structure, transporter bridges all work using the same fundamental mechanics. The gondola is suspended below the bridge by a series of steel cables, which attach to an overhead trolley. The trolley sits on a track, which runs the length of the bridge, and a winch system is used to draw the platform and its cargo back and forth across the waterway.

The gondolas have a large carrying capacity and can often transport several hundred people or several vehicles at once. They also provide an advantage over traditional bridges in that they can take passengers directly from ground level. If the riverbanks are very low, a long approach road is required to get vehicles to the correct altitude to cross a normal bridge. ⚙



Anchor arm
The bridge is counterbalanced by two anchor arms that extend away from the cantilever arms.

Track
A track between the two towers allows the trolley to move back and forth along the bridge.

Cantilever arm
The bridge is made from two cantilevers, each supported by a pair of towers.

Trolley
The platform is suspended below a trolley, which moves the gondola across in two and a half minutes.

At 259m (851ft) long, the Tees Transporter Bridge in Middlesbrough is one of the longest of its kind still in use

Anemometer
The gondola has equipment to detect wind speeds; if the wind reaches 56km/h (35mph) the bridge is closed for safety.

Cables
The gondola is attached to overhead rails by a network of steel cables.

Engine room
An engine room supplies power to the winch used to move the gondola.

Foundations
The bridge is supported by strong granite foundations buried deep beneath the ground.

Gondola
Passengers travel across the bridge using a large moving platform.

Carrying capacity
This gondola can carry a few hundred passengers or up to nine vehicles.

The science of cantilevers

The Tees Transporter Bridge in Middlesbrough is built using two cantilevers. The beams of a cantilever bridge are supported at only one end, and the entire load is transferred to support towers. Cantilever bridges are often made out of structural steel for its ability to resist stress, and crossbeams may also be included to distribute the load. The cantilever is supported by a steel or concrete tower, and is balanced by a second arm known as the anchor arm. The anchor arm is connected to the cantilever arm and extends in the opposite direction, providing a counterbalance to the unsupported end of the structure. The anchor arm is firmly linked to the ground by either a second tower or – in the case of the Tees Transporter Bridge – steel cables (see X-shaped structure on far left).

Five bridges that move

1 Drawbridge

Drawbridges were one of the first types of movable bridge. Attached to rope or chain and a counterweight, they are raised and lowered by turning a crank, and function not just as a bridge over a moat or ditch but also as a door.

2 Folding bridge

Folding bridges are made from several segments. As the bridge opens, the segments are pulled into a concertina by counterweights, forming a folded 'N' shape and allowing boats to pass underneath.

3 Bascule bridge

The arms of a bascule bridge like London's Tower Bridge swing up, so boats pass through the centre. They work in a similar manner to a seesaw, using a counterweight to move the arms upwards.

4 Tilt bridge

A tilt bridge has a curved deck, which rotates around its central axis. When a boat needs to pass, the bridge spins upwards, transforming the walkway into an arch for the vessel to travel beneath.

5 Submersible bridge

Instead of rising up, a submersible bridge, like that in the Corinth Canal in Greece, has a section that sinks below the water to allow boats to pass. This means no height restriction is imposed on the river traffic.

© Thinkstock; Alamy; Malte Bilauer; Peter Trimming

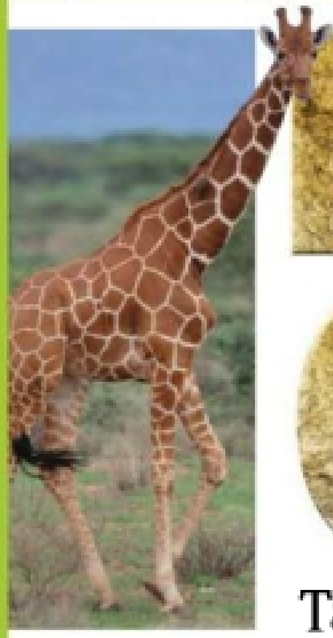
RECORD BREAKERS
HERCULEAN FELINE

410kg

WORLD'S BIGGEST BIG CAT

Hercules the liger (a cross between a lion and a tiger) weighs 410 kilograms (904 pounds) and stands 1.4 metres (4.6 feet) at the shoulder. He is 30 per cent bigger than the largest tiger.

DID YOU KNOW? *A single molar tooth from an elephant is the size of a house brick*



NATURE'S GIANTS

Taller, heavier, stronger – these are wild animals at large

Bigger is better. That's not just an expression, it's an evolutionary phenomenon called Cope's rule: animals tend to evolve into bigger animals. Over millions of years dinosaurs went from small reptiles into ground-shaking giants. After they went extinct, mammals became the dominant land animals and they too inexorably evolved from mouse-like critters into oversized behemoths such as a six-metre (20-foot) sloth Megatherium and the 12-ton-plus, horse-like Paraceratherium. When the ice ages came, the largest species were wiped out and smaller ones took over and started growing once again. The giant animals that exist today are just the latest swing of a pendulum that has been marking time over geological timescales.

Natural selection drives species to evolve larger bodies for several reasons. Being huge obviously makes it harder for you to be eaten by predators, but this is only part of it. The fiercest rivals most animals face are other members of their own species. The biggest males will be the ones to control the largest territories and have access to breeding females. Darwin thought the giraffe's long neck evolved so that it could reach the leaves on the tallest branches, but recent research has suggested that it may actually be because winning 'necking' contests is how males establish dominance over each other.

Eventually every species will reach a limit to its size. During the Carboniferous period around 300 million years ago, insects and other invertebrates grew to enormous sizes. There were dragonflies with 75-centimetre (30-inch) wingspans and a millipede-like creature called Arthropleura over two metres (6.6 feet) long.

But this was at a time when the oxygen concentration in the atmosphere was above 35 per cent, rather than the 21 per cent it is today. Eventually the oxygen level was so high that forests – and even swamps – caught fire with every lightning strike. As they burned, the oxygen in the air fell to much lower levels. Without sophisticated lungs and circulatory systems, these arthropod monsters simply couldn't get enough oxygen to sustain their massive bodies so they died out.

Even without such drastic environmental shifts, there are very real challenges for giant animals. Most predators generally eat animals smaller than themselves. This allows them to hunt abundant prey and achieve an easy kill with minimum risk to themselves. But carnivores heavier than about 21 kilograms (46 pounds) can't catch small animals fast enough to meet their food requirements. Instead they have to hunt quarry much larger than themselves. This is more dangerous and requires a radical shift in tactics. A large carnivore also has to cope with irregular mealtimes, with long periods of starvation followed by a stomach-stretching blowout.

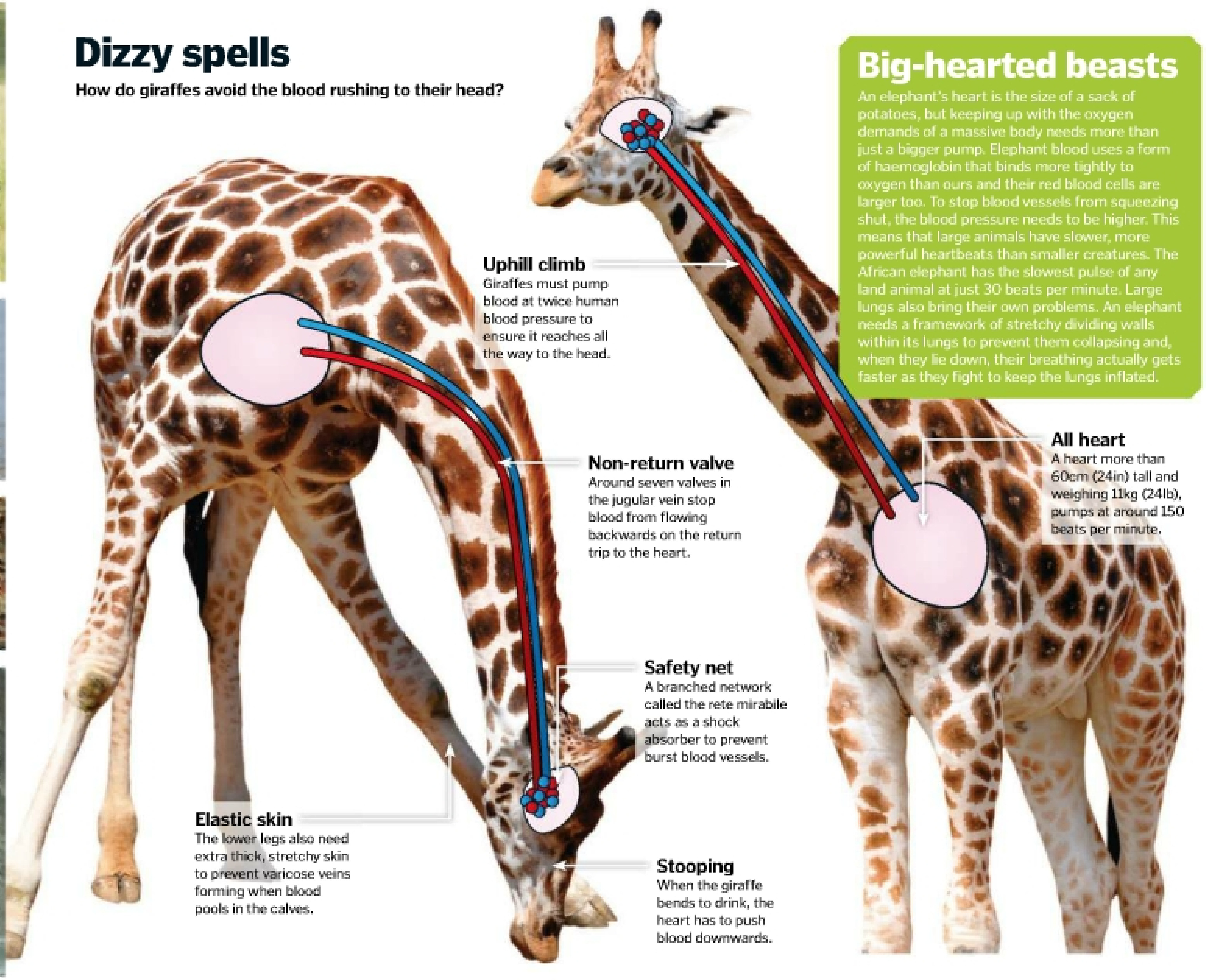
Herbivores, meanwhile, face challenges of their own. Plants are relatively poor in nutrients, so they need to eat a lot of them. Giant herbivores like elephants and rhinos can quickly overgraze an area if they don't constantly move on, and their large weight can compact the ground to the point where rainwater doesn't soak in properly and seeds find it difficult to become established. Elephants will uproot trees to get at the topmost leaves, turning savanna into grassland. Elephants can't survive on just grass though, so large populations of elephants can become the agents of their own destruction.

A massive body also creates problems for reproduction. If the young are born too small, they are vulnerable to predators; born too large and the extended gestation period places too much strain on the mother. Elephants spend almost two years pregnant and giraffes must be born with much shorter necks in order to prevent complications during birth.

But if nature has shown us one thing, it's that obstacles are there to be overcome. Around the world in virtually every animal group, colossal creatures have risen to the challenge and stomped on it. Let's meet nature's giants…

Dizzy spells

How do giraffes avoid the blood rushing to their head?



Uphill climb
Giraffes must pump blood at twice human blood pressure to ensure it reaches all the way to the head.

Non-return valve
Around seven valves in the jugular vein stop blood from flowing backwards on the return trip to the heart.

Safety net
A branched network called the rete mirabile acts as a shock absorber to prevent burst blood vessels.

Elastic skin
The lower legs also need extra thick, stretchy skin to prevent varicose veins forming when blood pools in the calves.

Stooping
When the giraffe bends to drink, the heart has to push blood downwards.

All heart
A heart more than 60cm (24in) tall and weighing 11kg (24lb), pumps at around 150 beats per minute.

Big-hearted beasts

An elephant's heart is the size of a sack of potatoes, but keeping up with the oxygen demands of a massive body needs more than just a bigger pump. Elephant blood uses a form of haemoglobin that binds more tightly to oxygen than ours and their red blood cells are larger too. To stop blood vessels from squeezing shut, the blood pressure needs to be higher. This means that large animals have slower, more powerful heartbeats than smaller creatures. The African elephant has the slowest pulse of any land animal at just 30 beats per minute. Large lungs also bring their own problems. An elephant needs a framework of stretchy dividing walls within its lungs to prevent them collapsing and, when they lie down, their breathing actually gets faster as they fight to keep the lungs inflated.

> "Within a given species or genus, the larger variants are normally found in the coldest climates"

Hippos spend the majority of the day in rivers and lakes to escape the Sun, feeding on the banks in the cool of night

The perfect temperature

Large animals have intrinsic protection against the cold. The bigger you are, the more heat is generated by your metabolism. Kodiak brown bears don't hibernate in the winter to avoid the freezing temperatures – they do it because there isn't enough food to support their voracious appetite. Within a given species or genus, the larger variants are normally found in the coldest climates – the Siberian tiger is the largest tiger subspecies, for example.

But in hot climates, being large presents the opposite problem: how to get rid of that excess heat? Hippos spend the day in rivers or lakes and only venture out at night to graze. The southern white rhino spends the hottest part of the day wallowing in a mudhole and even tigers will take a dip in the river to cool off – one of the only large cats that does this. Elephants swim too, but when they are on the open savanna their ears act as natural radiators, pumping hot blood through thin skin to shed heat.

Mighty appetites

An elephant already has to spend between 16 and 18 hours of every day just eating – that's more than 80 per cent of its waking hours! There simply isn't time to eat any more food than that. A big part of the problem is that an elephant's digestion is quite inefficient. In fact, elephant dung still has 50 per cent of the nutrients left in it and so it's a viable food source for hornbills, baboons and dung beetles. Gorillas can't digest plant cellulose either, but they don't have the stomach capacity to just munch indiscriminately. Instead they use their nimble fingers and teeth to strip the edible parts off a plant, like fruit, bark and roots.

For large carnivores, the problem is catching enough food. Tigers are only successful once out of every 10-20 hunting trips. On average they catch just a single deer a week, so they need to be able to eat huge amounts at a single sitting.

POLAR BEAR

Daily food required: 2kg (4.4lb)

Single sitting portion: 120kg (265lb)

GREEN ANACONDA

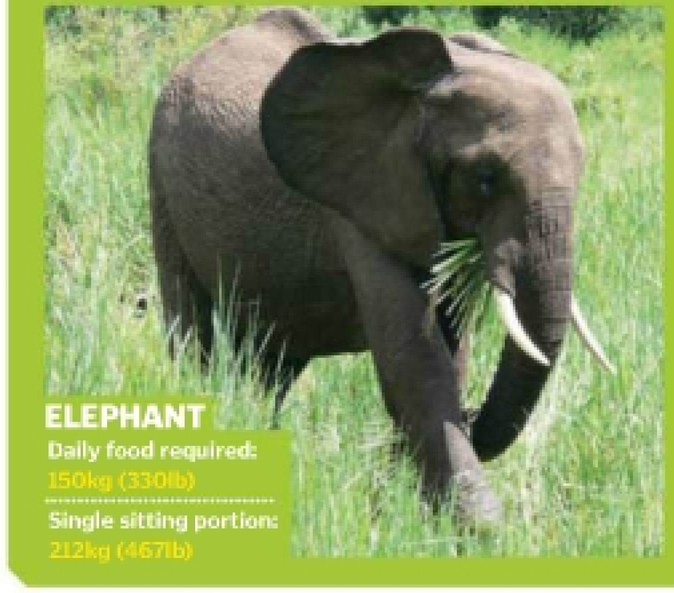
Daily food required: 0.2kg (0.4lb)

Single sitting portion: 30kg (66lb)

TIGER

Daily food required: 6kg (13lb)

Single sitting portion: 40kg (88lb)



ELEPHANT

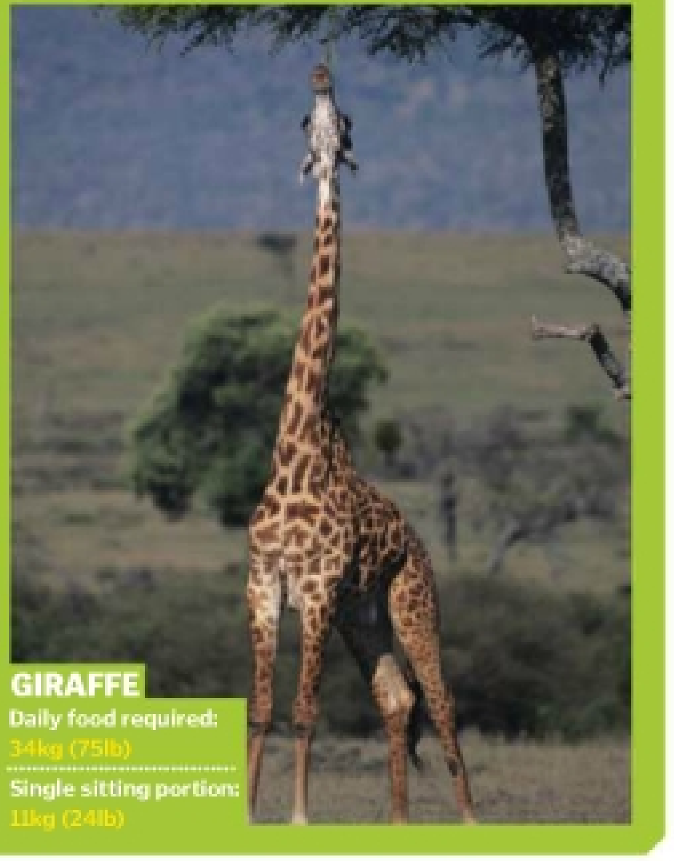
Daily food required: 150kg (330lb)

Single sitting portion: 212kg (467lb)

GORILLA

Daily food required: 18kg (40lb)

Single sitting portion: 6kg (13lb)



GIRAFFE

Daily food required: 34kg (75lb)

Single sitting portion: 11kg (24lb)

HEAD2HEAD

MARINE GIANTS

1. HEAVY

Giant Pacific octopus

Up to five metres (16 feet) across and weighing 50 kilograms (110 pounds), this ocean monster only lives up to five years.

2. HEAVIER

Ocean sunfish

Averaging a ton, this is the largest bony fish on the planet. Females lay 300 million eggs at a time – which is more than any other vertebrate.

3. HEAVIEST

Blue whale

Not just the largest animal alive today, but the largest animal to have ever lived, a blue whale is equivalent to the weight of about 30 elephants, ie 200 tons.

DID YOU KNOW? The giraffe has a prehensile tongue that is 0.5m (1.6ft) long! It's black to protect it from sunburn

Big game hunting

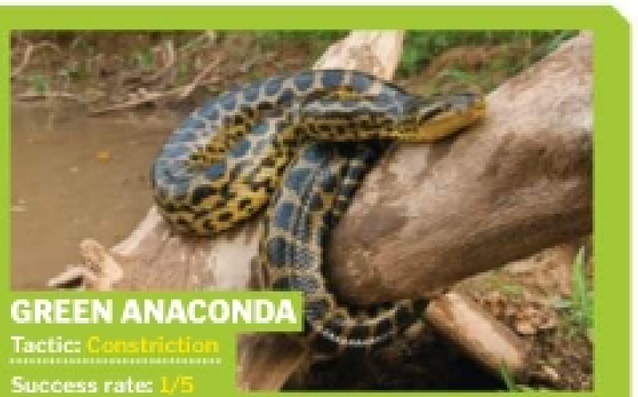
One of the biggest advantages of being large is that it protects you from predators. But if you are a predator yourself, extreme size can often be a disadvantage. The larger you are, the harder it is to sneak up on prey and the less manoeuvrable you are in comparison. Apex predators normally need huge hunting ranges to find enough food; golden eagles, for instance, patrol over 200 square kilometres (77 square miles) of moorland looking for carrion, fish and rodents, etc.

To overcome this, large predators need to be stealthy. Often they prefer to ambush their victims, rather than run them down. Anacondas lie in wait at watering holes, while brown bears will sit patiently in the river at the top of a salmon leap. Others rely on team tactics. Lions are famous for their group hunting techniques, but Philippine eagles also hunt in pairs, with one bird perching to distract a troop of monkeys, while the other swoops in from behind.

AFRICAN LION

Tactic: Teamwork

Success rate: 4/5



GREEN ANACONDA

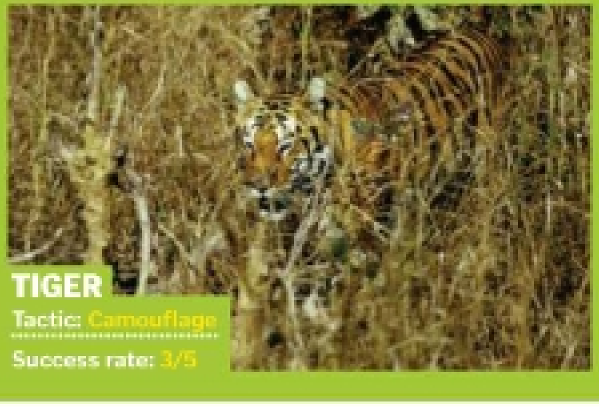
Tactic: Constriction

Success rate: 1/5

KODIAK BEAR

Tactic: Patience and timing

Success rate: 3/5



TIGER

Tactic: Camouflage

Success rate: 3/5

PHILIPPINE EAGLE

Tactic: Distraction/ambush

Success rate: 2/5

Like all ungulate animals (eg deer, goats, cows, etc) giraffes are digitigrade (ie they walk on tiptoes)

Don't ever race a giraffe!

The legs of a giraffe are two metres (6.6 feet) long but almost half of this is actually the foot. The joint that functions as a knee is anatomically equivalent to a wrist or ankle. The giraffe balances on the tips of its toenails, but to support its weight these toenail hoofs are 30 centimetres (12 inches) across. Giraffes can gallop at 60 kilometres (37 miles) per hour for short periods, while elephants hit the red line at just 25 kilometres (16 miles) per hour.

Because of the way that their legs must be positioned to support the body weight, elephants have very poor leverage and use a single running gait. Long-distance running is a problem for many very large animals. Tigers, for example, can cover as much as 32 kilometres (20 miles) in a single night's hunting, but they do it at an easy walk. To catch prey they must sneak to within 10-20 metres (33-66 feet) of the victim before they are in pouncing range.

> "Giant salamanders can live for over 30 years and keep growing throughout their lifetime"

THE STATS ELEPHANTS

HEIGHT 3.5m

WATER DRUNK PER DAY (LITRES) 85

MAX SKIN THICKNESS 3.8cm

AVERAGE TOTAL WEIGHT 6 tons

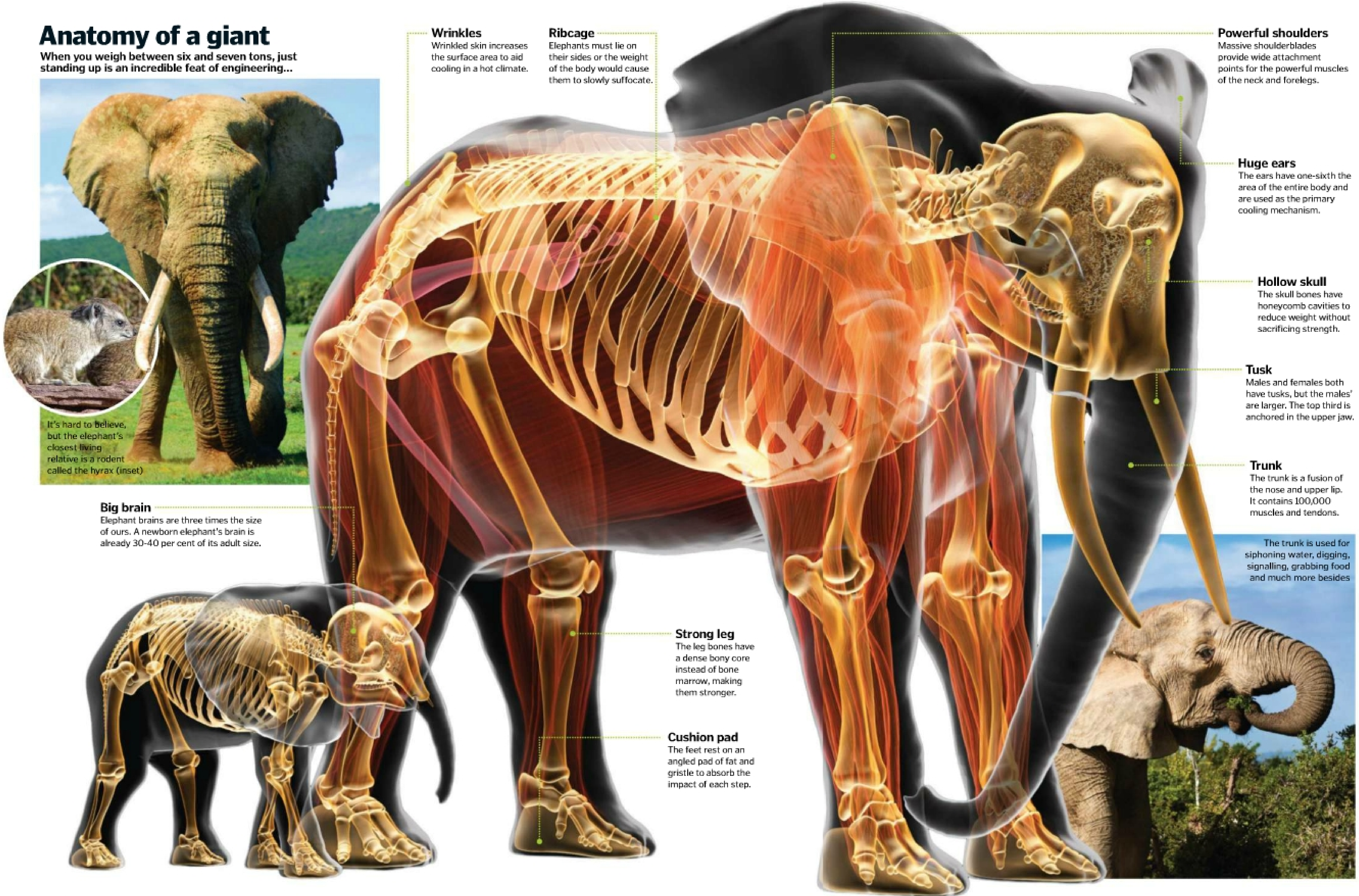
TUSK WEIGHT 65kg

BRAIN WEIGHT 5kg

DID YOU KNOW? *The white rhino has the widest nostrils of any land animal, with nasal passages larger than its brain!*

Anatomy of a giant

When you weigh between six and seven tons, just standing up is an incredible feat of engineering…



It's hard to believe, but the elephant's closest living relative is a rodent called the hyrax (inset)

Wrinkles Wrinkled skin increases the surface area to aid cooling in a hot climate.

Ribcage Elephants must lie on their sides or the weight of the body would cause them to slowly suffocate.

Powerful shoulders Massive shoulderblades provide wide attachment points for the powerful muscles of the neck and forelegs.

Huge ears The ears have one-sixth the area of the entire body and are used as the primary cooling mechanism.

Hollow skull The skull bones have honeycomb cavities to reduce weight without sacrificing strength.

Tusk Males and females both have tusks, but the males' are larger. The top third is anchored in the upper jaw.

Trunk The trunk is a fusion of the nose and upper lip. It contains 100,000 muscles and tendons.

Big brain Elephant brains are three times the size of ours. A newborn elephant's brain is already 30-40 per cent of its adult size.

Strong leg The leg bones have a dense bony core instead of bone marrow, making them stronger.

Cushion pad The feet rest on an angled pad of fat and gristle to absorb the impact of each step.

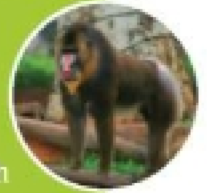
The trunk is used for siphoning water, digging, signalling, grabbing food and much more besides

More big beasts!

Hippopotamus

Hippos are more closely related to whales than they are to rhinos or elephants. They can weigh up to three tons and prefer to spend the day in the river, but on land they can easily outrun a human – so be wary!

Mandrill



The largest monkey, adult male mandrills can weigh over 35 kilograms (77 pounds). They eat mainly fruit, but also sometimes catch small animals and even deer, which they kill with a bite from their long canines.

Red kangaroo

The largest marsupial, red kangaroos can be taller than a man and weigh up to 90 kilograms (198 pounds). They are the only large animal that gets around by hopping. At full pelt, they can move at up to 71 kilometres (44 miles) per hour!

Southern elephant seal

They have the largest size difference between males and females of any land-breeding mammal: male elephant seals are six times heavier than females. A large adult male can weigh up to four tons. Their size has evolved because of brutal territorial contests with other males.

Saltwater crocodile

The largest reptile and also the most widely distributed crocodile species around the world. Males can reach over six metres (20 feet) long and weigh over a ton. They have the strongest bite of any animal alive – it's three and a half times stronger than a tiger's.

Chinese giant salamander

Giant salamanders can live for over 30 years and keep growing throughout their lifetime. Large specimens can be 1.5 metres (4.9 feet) long and weigh 50 kilograms (110 pounds). They have tiny eyes, but are very sensitive to vibration, which enables them to catch quick-moving fish and frogs.

Giant golden-crowned flying fox

Although tiny compared to the other animals here, this is the largest bat on Earth. It's under 1.2 kilograms (2.6 pounds), but can have a wingspan of 1.5 metres (4.9 feet). They mainly eat figs.

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5 TOP FACTS
VIEW FROM SPACE

Sierra Madre Oriental
1 This mountain range marks the border between the Coahuila and Nuevo León regions in Mexico. Satellite imagery reveals them to look like the spines of fossilised dinosaurs.

Baffin Island sea ice
2 From space these chunks of sea ice floating among tiny ice crystals, known as grease ice, look like swirling wispy white clouds when captured using satellite imagery.

Spider Crater
3 This impact crater in north Western Australia has leg-like ridges of tough sandstone which have stood the test of time better than the surrounding crater.

Polar auroras
4 When the aurora borealis/australis geomagnetic storms are viewed from space they somehow manage to look even more alien than they do when viewed from below.

Great Barrier Reef
5 The magnificent blue-green glow of corals in the Great Barrier Reef off the coast of Queensland are particularly impressive when viewed using satellite imagery.

DID YOU KNOW? *Richat's outer rings are the youngest while those at the core indicate significantly older rock*

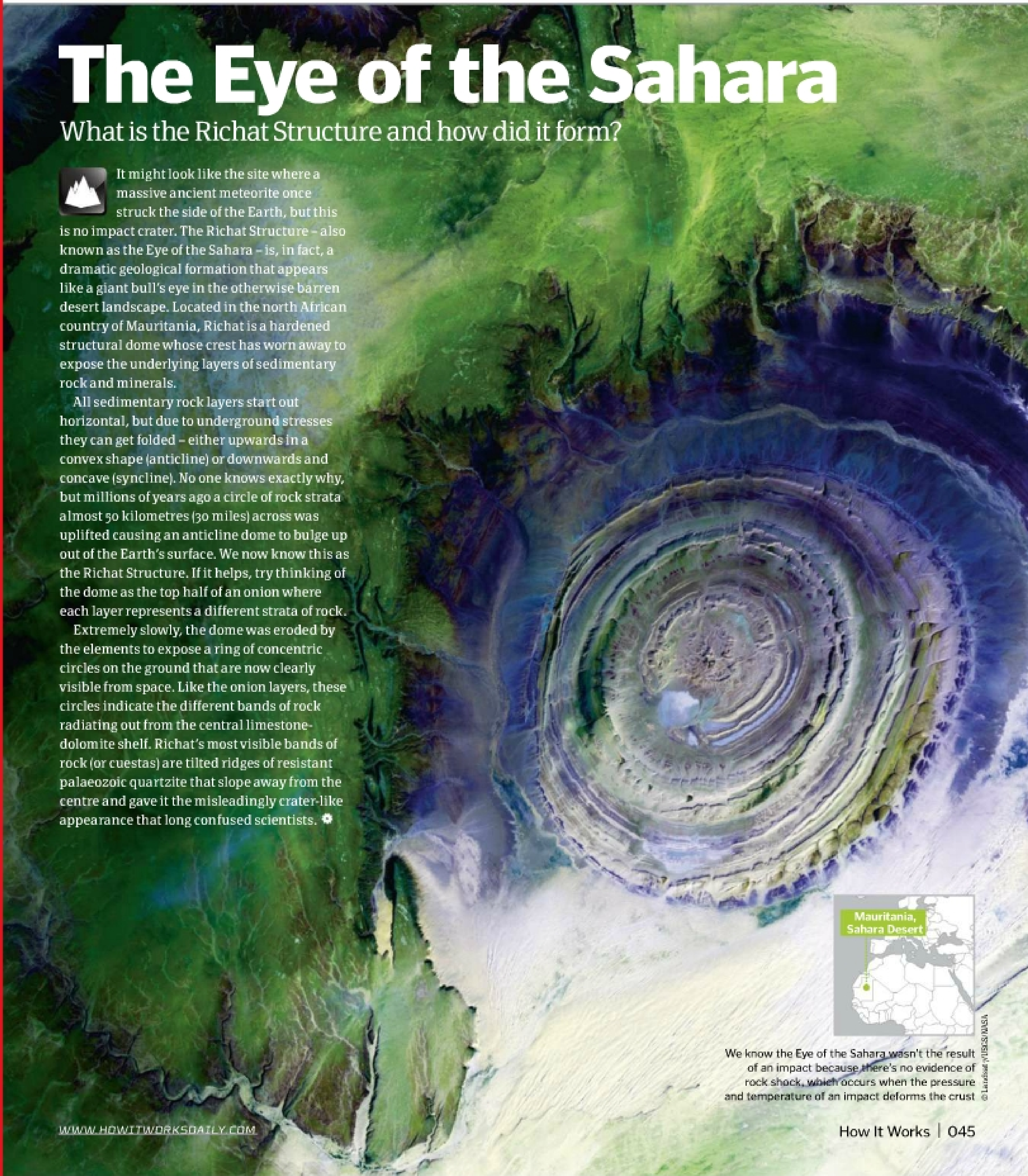
The Eye of the Sahara

What is the Richat Structure and how did it form?

It might look like the site where a massive ancient meteorite once struck the side of the Earth, but this is no impact crater. The Richat Structure – also known as the Eye of the Sahara – is, in fact, a dramatic geological formation that appears like a giant bull's eye in the otherwise barren desert landscape. Located in the north African country of Mauritania, Richat is a hardened structural dome whose crest has worn away to expose the underlying layers of sedimentary rock and minerals.

All sedimentary rock layers start out horizontal, but due to underground stresses they can get folded – either upwards in a convex shape (anticline) or downwards and concave (syncline). No one knows exactly why, but millions of years ago a circle of rock strata almost 50 kilometres (30 miles) across was uplifted causing an anticline dome to bulge up out of the Earth's surface. We now know this as the Richat Structure. If it helps, try thinking of the dome as the top half of an onion where each layer represents a different strata of rock.

Extremely slowly, the dome was eroded by the elements to expose a ring of concentric circles on the ground that are now clearly visible from space. Like the onion layers, these circles indicate the different bands of rock radiating out from the central limestone-dolomite shelf. Richat's most visible bands of rock (or cuestas) are tilted ridges of resistant palaeozoic quartzite that slope away from the centre and gave it the misleadingly crater-like appearance that long confused scientists. ✪



We know the Eye of the Sahara wasn't the result of an impact because there's no evidence of rock shock, which occurs when the pressure and temperature of an impact deforms the crust

© Landsat7/USGS/NASA

> “Such is the power of glaciers that the bottoms of fjords are often deeper than the ocean they open into”

HEAD 2 HEAD

RECORD FJORDS

1. LONGEST

Scoresby Sund

Located on the east coast of Greenland, the huge Scoresby Sund inlet is believed to be the longest fjord system found anywhere in the world.

2. NARROWEST

Nærøyfjord

Branching off Norway's larger and more famous Sognefjord near Bergen, the Nærøyfjord is just 250 metres (820 feet) wide at its narrowest point.

3. DEEPEST

Fiordo Baker

This fjord in Chile boasts the largest-known over-deepening of 1,344 metres (4,409 feet) – that equates to about three Empire State Buildings!

DID YOU KNOW? *The milky-turquoise colour of the glacier meltwater in a fjord is caused by super-fine debris called 'rock flour'*

How fjords form

As a product of the epic clash between ice and rock, find out how these amazing valleys are created

Fjords are long, steep-sided coastal valleys that are flooded by the sea. The majority of fjords developed during the last ice age, peaking approximately 20,000 years ago. Glaciers dominated the landscape, snaking their way to the ocean and tearing through anything that stood in their path. These massive valleys are typically found in mountainous, coastal areas of the Atlantic and Pacific oceans, and are common in Norway, Sweden, Greenland, Canada, Chile, New Zealand and the US state of Alaska.

As a glacier carved its way through the rock, it cut a distinctive U-shaped valley. The floor was flat and the sides were steep and high. As the massive river of ice – which could reach up to three kilometres (1.9 miles) thick – bore through the valley floor, it picked up rocky debris and carried it along for the ride, adding to the glacier's rock-shattering abrasive power. This rubble eventually made its way to the head of the glacier and was pushed in front of it as the glacier travelled – known as a terminal moraine. Such is the sheer power of the glacier to gouge out rock that the bottoms of fjords are often deeper than the ocean that they open into. For example, the deepest point of the Sognefjord in Norway is approximately 1,300 metres (4,265 feet) below sea level whereas the sill is just 100 metres (328 feet) below sea level. As the ice age came to a close, the oceans flooded into these extra-deep glaciated valleys, forming what we now know as fjords.

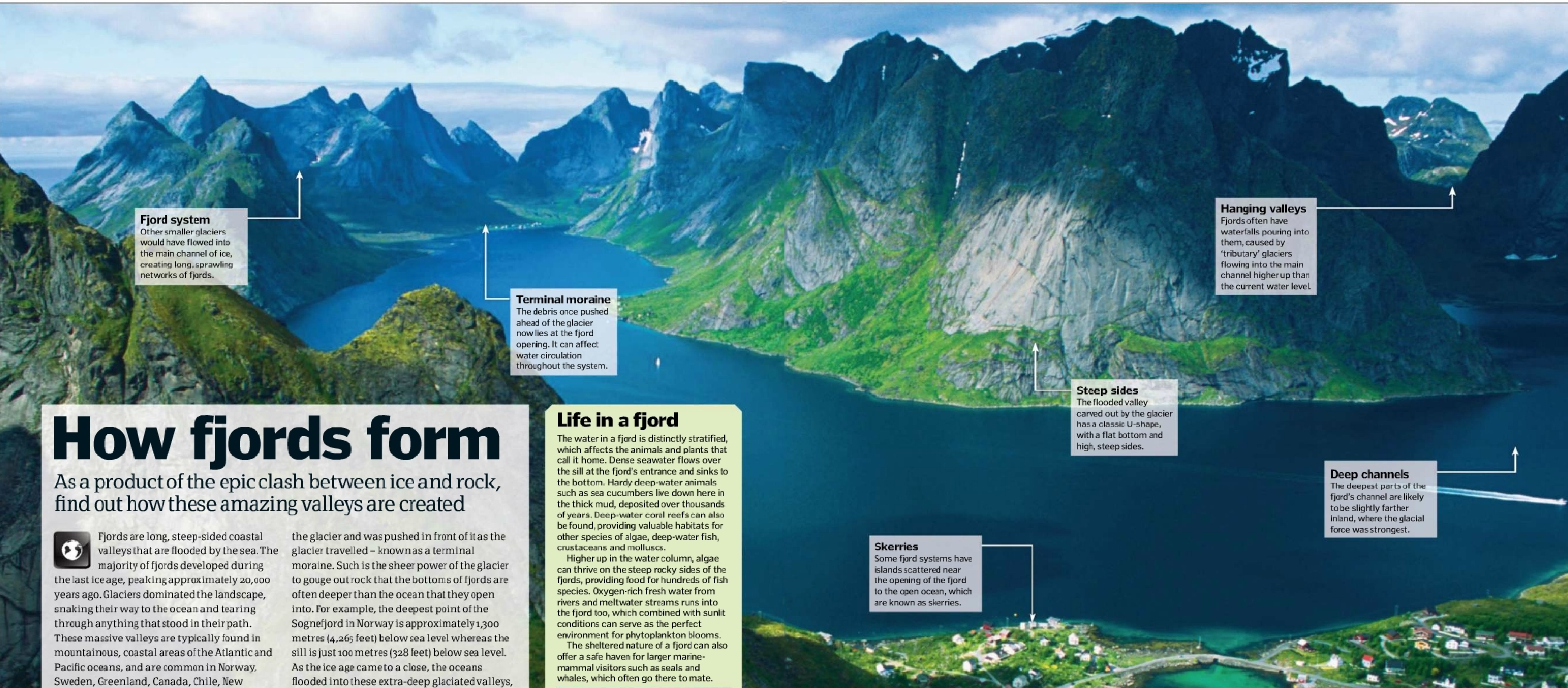
It's the rock formations of a glaciated landscape that are left for us to see today. The glacial moraine will still be present at the entrance of a fjord – a large sill acting as a barrier between fjord and open ocean. There are also other features such as skerries, which are rocky islands within a fjord that can be both large and mountainous or small and treacherous to navigate in a boat.

Life in a fjord

The water in a fjord is distinctly stratified, which affects the animals and plants that call it home. Dense seawater flows over the sill at the fjord's entrance and sinks to the bottom. Hardy deep-water animals such as sea cucumbers live down here in the thick mud, deposited over thousands of years. Deep-water coral reefs can also be found, providing valuable habitats for other species of algae, deep-water fish, crustaceans and molluscs.

Higher up in the water column, algae can thrive on the steep rocky sides of the fjords, providing food for hundreds of fish species. Oxygen-rich fresh water from rivers and meltwater streams runs into the fjord too, which combined with sunlit conditions can serve as the perfect environment for phytoplankton blooms.

The sheltered nature of a fjord can also offer a safe haven for larger marine-mammal visitors such as seals and whales, which often go there to mate.



Fjord system
Other smaller glaciers would have flowed into the main channel of ice, creating long, sprawling networks of fjords.

Terminal moraine
The debris once pushed ahead of the glacier now lies at the fjord opening. It can affect water circulation throughout the system.

Hanging valleys
Fjords often have waterfalls pouring into them, caused by 'tributary' glaciers flowing into the main channel higher up than the current water level.

Steep sides
The flooded valley carved out by the glacier has a classic U-shape, with a flat bottom and high, steep sides.

Deep channels
The deepest parts of the fjord's channel are likely to be slightly farther inland, where the glacial force was strongest.

Skerries
Some fjord systems have islands scattered near the opening of the fjord to the open ocean, which are known as skerries.

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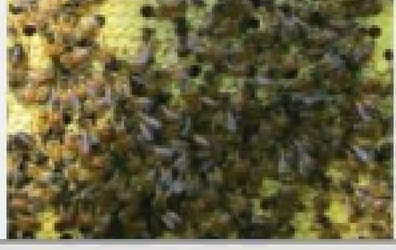
STRANGE BUT TRUE
HORNETS BEE-WARE

How can bees get their own back on hornets?

A Cook them **B** Drown them **C** Make fun of them



Answer:
Bees do have one secret weapon. They can swarm around the scout and vibrate to turn up the heat. Bees can withstand 48 degrees Celsius (118 degrees Fahrenheit), but hornets can only stand 46 degrees Celsius (115 degrees Fahrenheit) and so roast.

DID YOU KNOW? *Petrichor is taken from the Greek for stone (petra) and the fluid found in the veins of Greek gods (ichor)*

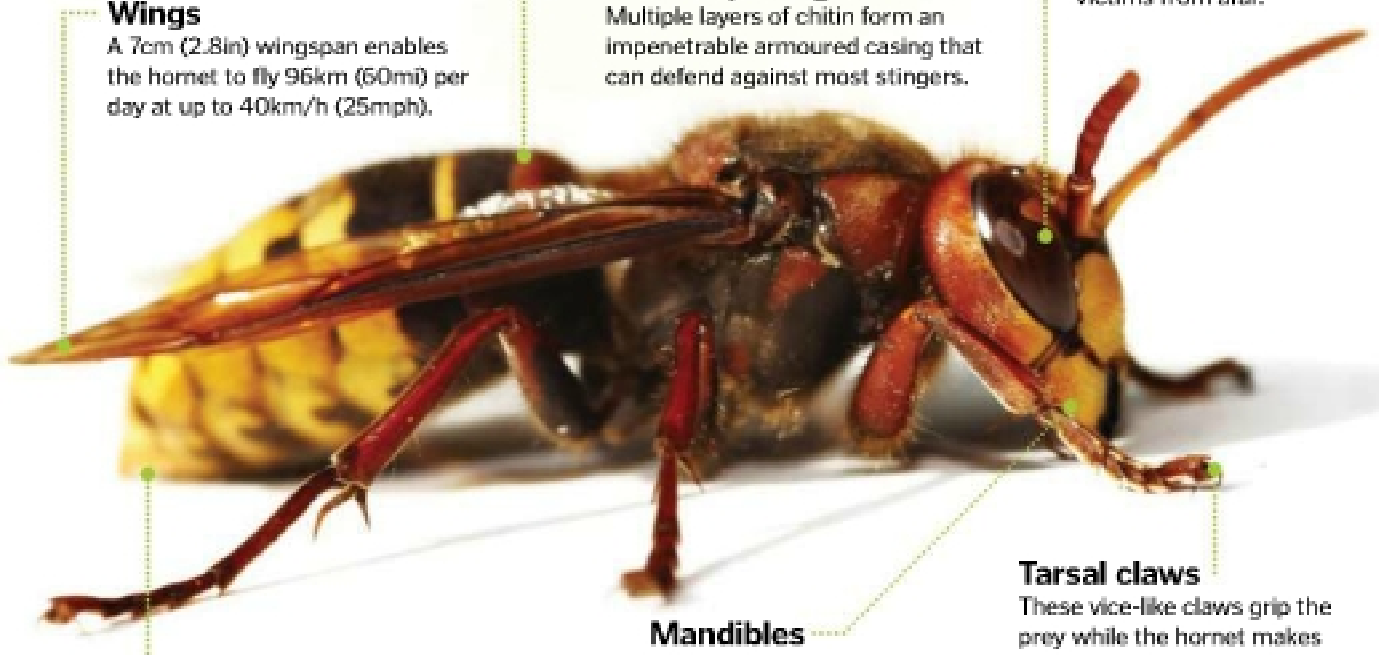
Hornets vs honeybees

How 30 giant hornets can exterminate a colony of 30,000 honeybees in mere hours

Giant hornets have a taste for honeybee larvae and pupae, which they feed to their own young. Once a hornet scout locates a honeybee nest it releases a potent pheromone to signal the location to other hornets. Upon their arrival, as few as 30 giant hornets can wipe out an entire bee colony a thousand times larger. The hornets are four to five times the size of the honeybees and, with every minute that passes, one hornet will massacre at least five bees. Strong tarsal claws and powerful mandibles mean the invaders are capable of ripping bee heads from bodies and simply casting them aside. The bees do everything they can to protect their hive – attempting to sting through the hornets' impenetrable armour – but within three hours the colony is wiped out. The hornets now have access to enough honey to gorge themselves, and all the bee larvae and pupae to take back to their offspring.

Japanese giant hornet biology

A consummate killer, the hornet is built for mass murder



Wings
A 7cm (2.8in) wingspan enables the hornet to fly 96km (60mi) per day at up to 40km/h (25mph).

Armour plating
Multiple layers of chitin form an impenetrable armoured casing that can defend against most stingers.

Compound eyes
Hornets have extremely good eyesight enabling them to spot potential victims from afar.

Stinger
This pumps out a large dose of excruciating venom that contains an enzyme potent enough to dissolve human skin. Japanese giant hornets kill 40 Japanese people every year.

Mandibles
Powerful jaws are capable of beheading bees with a single slice.

Tarsal claws
These vice-like claws grip the prey while the hornet makes short work of rending multiple victims in seconds.

The smell of rain

Find out why precipitation creates a distinctive aroma that's the same all over the world

It's possible to smell rain before it has even fallen. Lightning has the power to split atmospheric nitrogen and oxygen molecules into individual atoms. These atoms then react to form nitric oxide, which in turn can interact with other chemicals to form ozone – the aroma of which is a bit like chlorine and a specific smell we've grown to associate with rain. When the scent carries on the wind, we can predict the rain before it falls.

Another smell associated with rain is petrichor – a term coined by a couple of Australian scientists in the mid-Sixties. After a dry spell of weather, the first rain that falls brings with it a very particular aroma that is the same no matter where you are. Two chemicals are responsible for the production of this indescribable odour called petrichor. One of the two chemicals is released by a specific bacteria found in the earth; the other is an oil secreted by thirsty plants. These compounds combine on the ground and, when it rains, the smell of petrichor will fill your nostrils.

"For some varieties of salmon runs can cover staggering distances of up to 3,200 kilometres [2,000 miles]"

5 TOP FACTS GREAT MIGRATIONS

Arctic terns
1 The Arctic tern's annual round trip from the Arctic Circle down to the Antarctic Circle in the south sees this little seabird travel at least 32,000 kilometres (20,000 miles).

Monarch butterflies
2 Like the sockeye salmon, the monarch butterfly also embarks on a one-off migration travelling vast distances of up to 4,800 kilometres (3,000 miles).

Wildebeest
3 Fuelled by hunger, 1.5 million wildebeest migrate in a giant 2,900-kilometre (1,800-mile) loop in eastern Africa every year. They are following the rains that replenish the grass.

Red land crabs
4 Millions of the red land crabs native to Christmas Island crawl out of the forests before the monsoon season and march sideways for up to a week towards the shore.

Sperm whales
5 Groups of 50-ton adult sperm whale bachelors embark upon epic journeys that can see them clocking up thousands of miles before being reunited with the female whales.

DID YOU KNOW? A fish has the same number of scales all its life; as the fish grows so too does each scale

The life cycle of a sockeye salmon

Discover the epic journey a salmon undertakes from birth to death

The life aquatic is something of an adventurous existence if you're a migratory Pacific salmon such as the sockeye. While most of its life is spent out in the ocean, such seasonal changes as the shortening of the length of a day trigger the once-in-its-lifetime migration back to the freshwater rivers of its youth.

The annual salmon run performed by the adult fish takes place usually in late-spring to summer. This instinctive behaviour, written in the genes, sees the salmon battle its way from the ocean back along estuaries, past fishermen's hooks, up treacherous bear-lined rapids and on to the gravel beds of the stream where it was born. For some varieties of salmon runs can cover staggering distances of up to 3,200 kilometres (2,000 miles) up the Yukon River. It's unknown quite how the salmon knows where it's heading, but it's thought it could be following its nose and tracking a certain familiar scent.

The death-defying voyage is exhausting for the adult salmon and, once it arrives at the spawning ground and lays/fertilises its eggs, it will die. The new eggs develop into the next generation of salmon that will embark on precisely the same cycle of life.

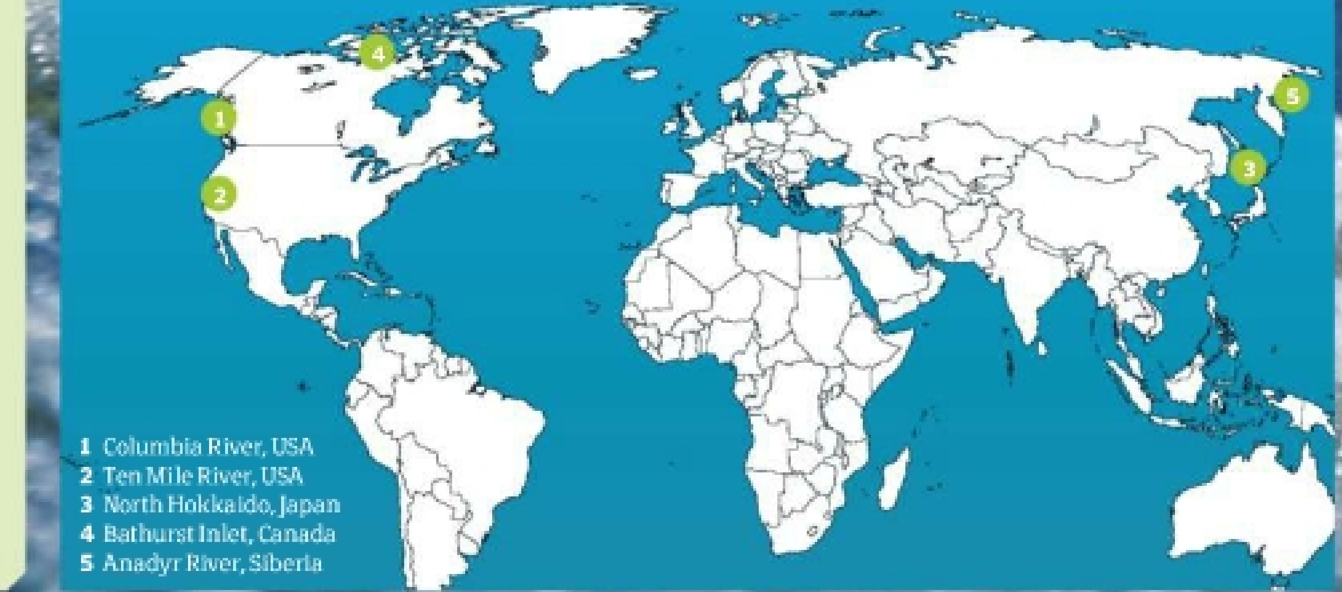
Around six to nine weeks after the eggs have been laid and fertilised in the gravel, the young will begin to hatch in the freshwater where they will remain developing for up to three years. First hatching as alevins they develop from defenceless small fry through to well-camouflaged parrs, then smolts and eventually to adults. After that they will migrate to the ocean for their first taste of saltwater where they will continue their growth into maturity. ✽

Ladders for fish

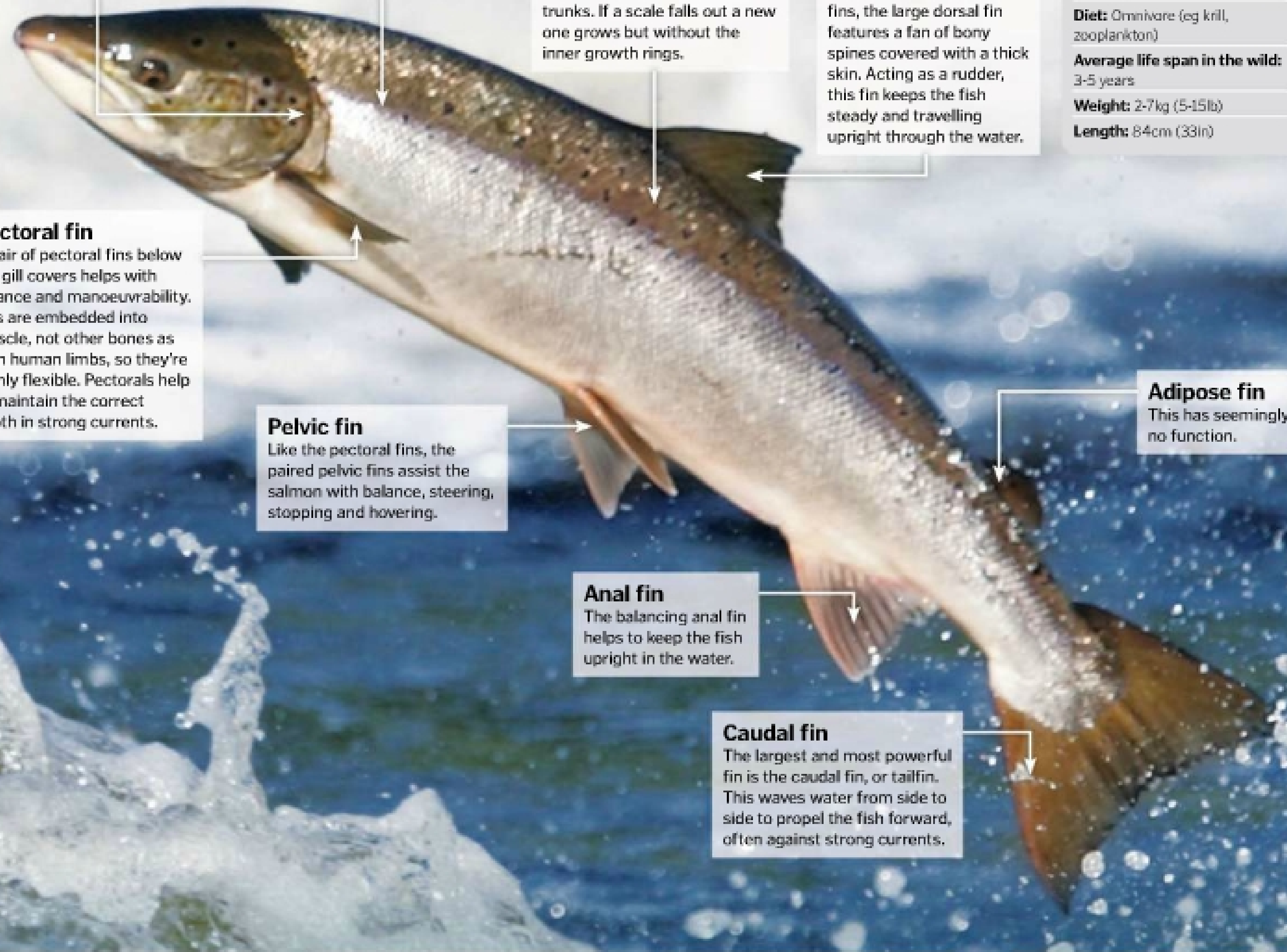
When salmon make their way back upstream to spawn, they can encounter a number of manmade barriers, such as dams and locks. To ensure the fish can progress, humans have built stepped channels that go over or around the obstructions. Known as fish ladders these help the salmon overcome otherwise impassable obstacles and carry on the rest of their perilous journey. The most common type of fish ladder looks like a long staircase of mini waterfalls up which the fish can leap, but other varieties include elevators, pools-and-weirs and baffles.

The Bonneville Dam on the Columbia River is a major salmon thoroughfare from the Pacific to freshwater spawning areas between Oregon and Washington. Hundreds of thousands of salmon take this route every year so the addition of the Bonneville fish ladder means these aquatic commuters can get where they need to go.

Where do sockeye salmon live?



1 Columbia River, USA
2 Ten Mile River, USA
3 North Hokkaido, Japan
4 Bathurst Inlet, Canada
5 Anadyr River, Siberia



Gill cover
Also called the operculum, this hard but flexible outer lining shields the gills. When the fish gulps in water, it seals off its mouth and throat to allow the water to pass over its gills, which absorb oxygen.

Lateral line
This is a series of fluid-filled canals (similar to what we have in our ears), which sense vibrations through the water and help the fish hear, or distinguish movements in the water and the direction in which it is flowing.

Scales
These overlapping plates provide flexible protective body armour against predators. Scales grow in at the fry stage of life. As they develop, they form rings like you see in tree trunks. If a scale falls out a new one grows but without the inner growth rings.

Dorsal fin
Like the salmon's other fins, the large dorsal fin features a fan of bony spines covered with a thick skin. Acting as a rudder, this fin keeps the fish steady and travelling upright through the water.

Pectoral fin
A pair of pectoral fins below the gill covers helps with balance and manoeuvrability. Fins are embedded into muscle, not other bones as with human limbs, so they're highly flexible. Pectorals help to maintain the correct depth in strong currents.

Pelvic fin
Like the pectoral fins, the paired pelvic fins assist the salmon with balance, steering, stopping and hovering.

Adipose fin
This has seemingly no function.

Anal fin
The balancing anal fin helps to keep the fish upright in the water.

Caudal fin
The largest and most powerful fin is the caudal fin, or tailfin. This waves water from side to side to propel the fish forward, often against strong currents.

The statistics…

Sockeye salmon

Binomial: Oncorhynchus nerka
Type: Fish
Diet: Omnivore (eg krill, zooplankton)
Average life span in the wild: 3-5 years
Weight: 2-7kg (5-15lb)
Length: 84cm (33in)

Life stages of a salmon

A sockeye goes through a number of dramatic physical – not to mention geographical – changes in its lifetime…

Eggs
The tiny translucent eggs spawned in the gravel beds of freshwater rivers and streams are a pinkish-orange colour. Each male salmon fertilises over 2,000 eggs, which hatch after a few weeks.

Alevin
An alevin hatches out of the soft eggshell but remains hidden in the gravel for another month. It will feed on a nutrient-rich yolk sac that remains attached to the small alevin's body, until it is absorbed.

Fry
The salmon is now starting to look like a fish. At five to ten weeks old, it leaves the gravel nest and learns to swim and feed on minuscule aquatic insects. At this point the salmon are very vulnerable.

Parr
After a few months, when the fish is about 15cm (6in), the fry becomes a parr. It's still vulnerable and so develops dark vertical stripes on its sides for camouflage. It will remain at this stage for up to three years.

Smolt
By the time the salmon is one to three years old, it no longer bears any stripes but appears silver. Smolts head for the sea, and in the estuary undergo smoltification as they adjust to the saltwater.

Adult
Once it gets to the ocean, the adult quickly reaches maturity. The skin is silvery blue with black speckles while it lives at sea, but when it returns to freshwater to spawn it turns red with a greenish head.

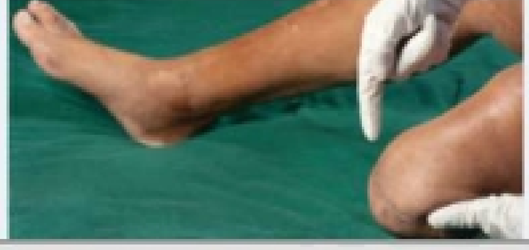
Spawning adult
The adults then make the perilous trek from ocean to stream. The spawning female digs a nest called a redd into which she lays her eggs for a male to fertilise. Within about two weeks the fish will have died.

© Alamy; Corbis

STRANGE BUT TRUE
LIMB LOSS CULPRIT

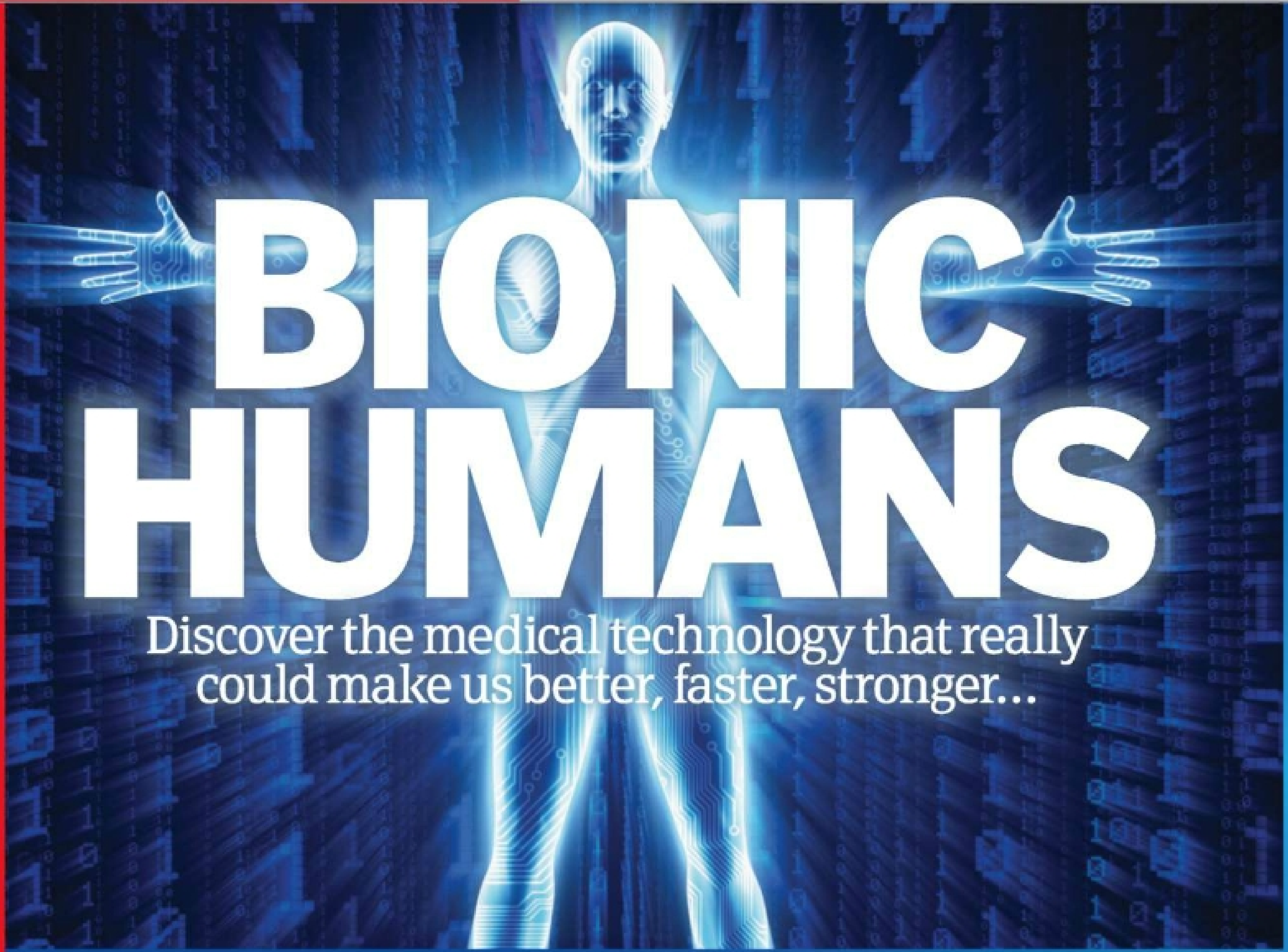
What is the number one cause of limb amputation?

A Car accident **B** Diabetes **C** Lightning



Answer:
Diabetes is the leading cause of lower limb amputation. High blood sugar damages the nerves and blood vessels in the feet, which can lead to ulcers and eventually gangrene.

DID YOU KNOW? *An artificial heart implant operation costs about £80,000 [$125,000] and £11,500 [$18,000] a year to maintain*



BIONIC HUMANS

Discover the medical technology that really could make us better, faster, stronger…

Bionics experts attempt to build mechanical and electronic devices to mimic biological functions. With the exception of the brain, the human body can essentially be broken down and rebuilt using a combination of mechanical, electronic and biological technologies.

A bionic limb strips human biology back to its constituent parts. Tough materials like aluminium and carbon fibre replace the skeleton, motors and hydraulics move the limb, while springs replace the tendons that store and release elastic energy. A computer controls motion and wires relay electrical signals, as nerves would have done in a real limb. Users are now even able to control these limbs with their minds (see 'The power of thought').

Technology is also in development to replace individual muscles and tendons following injury. The synthetic muscles are made from a polymer gel, which expands and contracts in response to electrical currents, much like human muscle. The tendons are made from fine synthetic fibres designed to imitate the behaviour of connective tissue.

The mechanical nature of limbs makes them excellent candidates for building robotic counterparts, and the same applies to the human heart. The two ventricles, which supply blood to the body and lungs, are replaced with hydraulically powered chambers. However, it's not just the mechanical components of the human body that can be replaced; as time goes on, even parts of the complex sensory system can be re-created with technology.

Cochlear implants, for example, use a microphone to replace the ear, while retinal implants use a video camera to stand in for the human eye. The data that they capture is then processed and transformed into electrical impulses, which are delivered to the auditory or optic nerve, respectively, and then on to the brain. Bionic touch sensors are also in development. For example, the University of California, Berkeley, is developing 'eSkin' – a network of pressure sensors in a plastic web. This could even allow people to sense touch through their bionic limbs.

Replacing entire organs is one of the ongoing goals of bionic research. However, breaking each organ down and re-creating all of its specialised biological functions is challenging.

If only part of an organ is damaged, it's simpler to replace the loss of function using bionics. In type 1 diabetes, the insulin-producing beta cells of the pancreas are destroyed by the immune system. Some patients are now fitted with an artificial pancreas: a computer worn externally, which monitors blood sugar and administers the correct dose of insulin as required.

Entire organ replacements are much more complicated, and scientists are turning back to biology to manufacture artificial organs. By combining 3D printing with stem cell research, we are now able to print cells layer by layer and build up tissues. In the future, this could lead to customised organ transplants made from the recipient's very own cells.

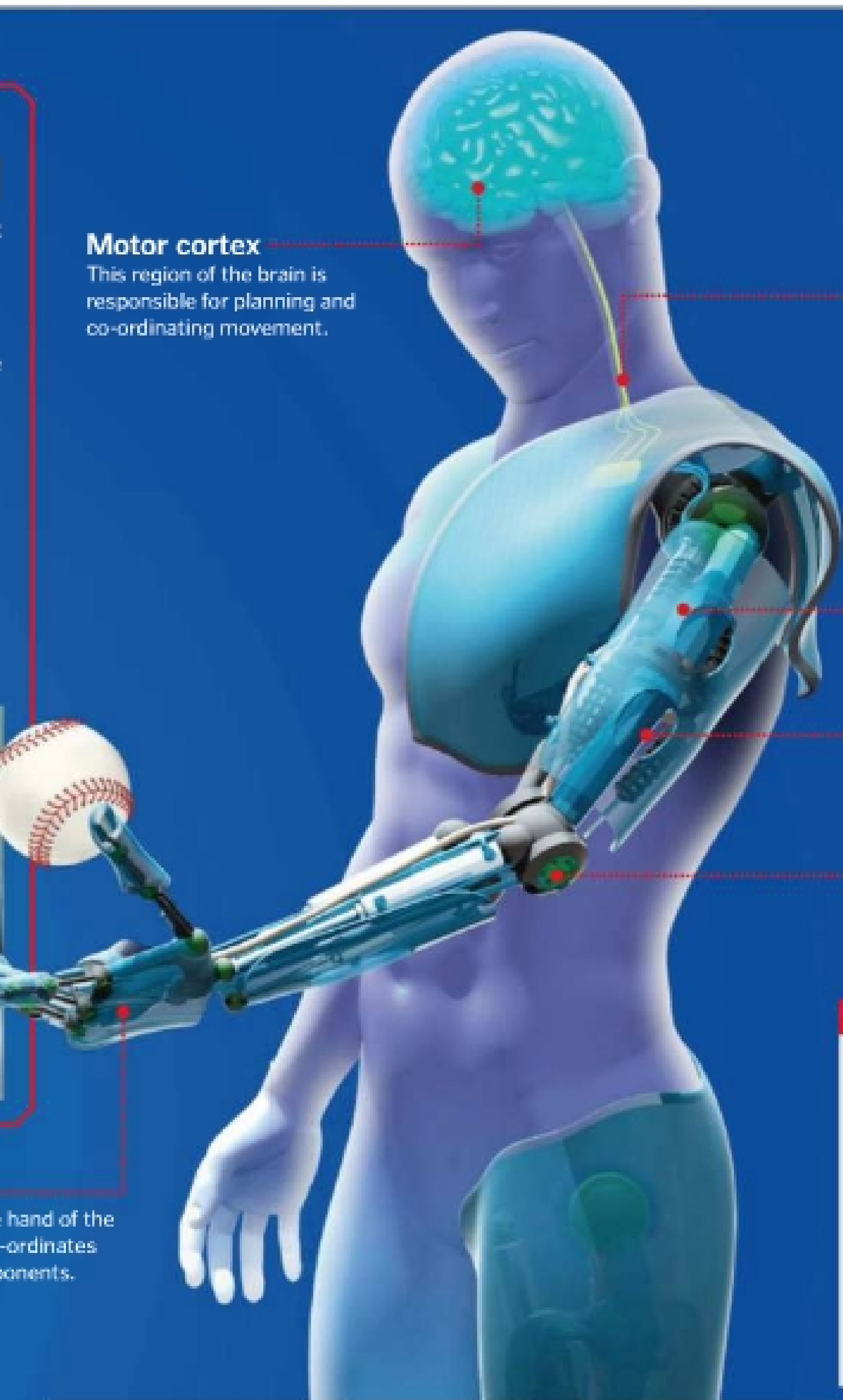
Advances in bionics mean that already limbs are emerging that exceed human capabilities for weight bearing and speed. That said, the sheer complexity of our internal organs and how they interact means that it is not yet possible to fully replace man with machine. But maybe it's just a matter of time…

The power of thought explained

Cutting-edge bionic limbs currently in development allow the user to control movements with their own thoughts. Technically called 'targeted muscle reinnervation' it's a groundbreaking surgical technique that rewires the nerves in an amputated limb. The remaining nerves that would have fed the missing arm and hand are rerouted into existing muscles. When the user thinks about moving their fingers, the muscles contract, and these contractions generate tiny electrical signals that can be picked up by the prosthetic.

The prosthetic is then programmed to respond to these muscle movements, taking each combination of signals and translating it into mechanical movement of the arm. Some of the most sophisticated have 100 sensors, 26 movable joints and 17 motors, all co-ordinated by a computer built into the prosthetic hand.

A scientist controls a wheelchair using a brain-machine interface



Motor cortex
This region of the brain is responsible for planning and co-ordinating movement.

Rerouted nerves
The nerves that used to feed the missing limb are rewired into existing muscles.

Sensors
Sensors pick up tiny electrical signals when the user thinks about moving.

Motors
A series of motors replace the biological function of muscles.

Joints
Joints are designed to match the natural range of human motion.

Computer
A computer in the hand of the prosthetic arm co-ordinates all the other components.

Learn more

If this bionics feature piques your interest, why not visit London's FutureFest (28-29 September 2013) where you can witness compelling talks, cutting-edge shows, technology displays and interactive performances, hearing from such speakers as 'bionic man' Bertolt Meyer. For more information visit: **futurefest.org.**

The right materials

One of the most important factors in biomedical engineering is biocompatibility – the interaction of different materials with biological tissues.

Implanted materials are often chosen because they are 'biologically inert' and as a result they don't provoke an immune response. These can include titanium, silicone and plastics like PTFE. Artificial heart valves are often coated in a layer of mesh-like fabric made from the same plastic used for soft drink bottles – Dacron. In a biological context, the plastic mesh serves as an inert scaffold, allowing the tissue to grow over the valve, securing it in place. Some scaffolds used in implants are even biodegradable, providing temporary support to the growing tissue, before harmlessly dissolving into the body.

Bionic limbs are worn externally, so their materials are chosen for strength and flexibility as opposed to biocompatibility. Aluminium, carbon fibre and titanium are all used as structural components, providing huge mechanical strength.

Artificial heart valves are often made from metal, such as titanium or stainless steel

> "Some of the newest technologies are so advanced they outperform their biological counterparts"

KEY DATES

BIONICS FIRSTS

500 BCE The first known mention of a wooden prosthetic limb, worn by a prisoner after his foot was amputated.

1957 The first cochlear implant is created. Sounds are unprocessed, but it does help with lip reading.

1982 The first successful artificial heart implant operation is performed at the University of Utah.

2011 The first artificial trachea transplant takes place in Sweden, using a synthetic scaffold coated in stem cells.

2013 The Argus II retinal implant is licensed, enabling patients with retinitis pigmentosa to see again.

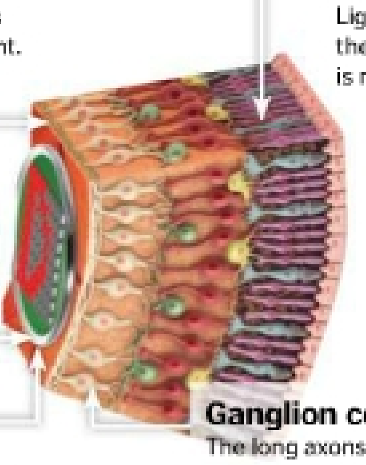
DID YOU KNOW? In 1812 a prosthetic arm was invented that could be moved using cables attached to the opposite shoulder

Building a bionic human

Advances in technology make it possible to build limbs with components that mimic the function of the skeleton, musculature, tendons and nerves of the human body. Meanwhile, the sensory system can be replicated with microphones, cameras, pressure sensors and electrodes. Even that most vital organ, the heart, can be replaced with a hydraulic pump. Some of the newest technologies are so advanced that the components actually outperform their biological counterparts.

Retinal implant

Argus II, Second Sight
A camera mounted on a pair of glasses captures real-time images and transmits them wirelessly to an implant on the retina. The implant contains 60 electrodes and, depending on the image, will generate different patterns of electrical signals, which are then sent to the remaining healthy retinal cells. These cells are activated by the signals, and carry the visual information to the brain for processing.



Interface
Nerve cells respond to electrical signals made by the implant.

Wireless technology
Video signals are sent wirelessly to the implant.

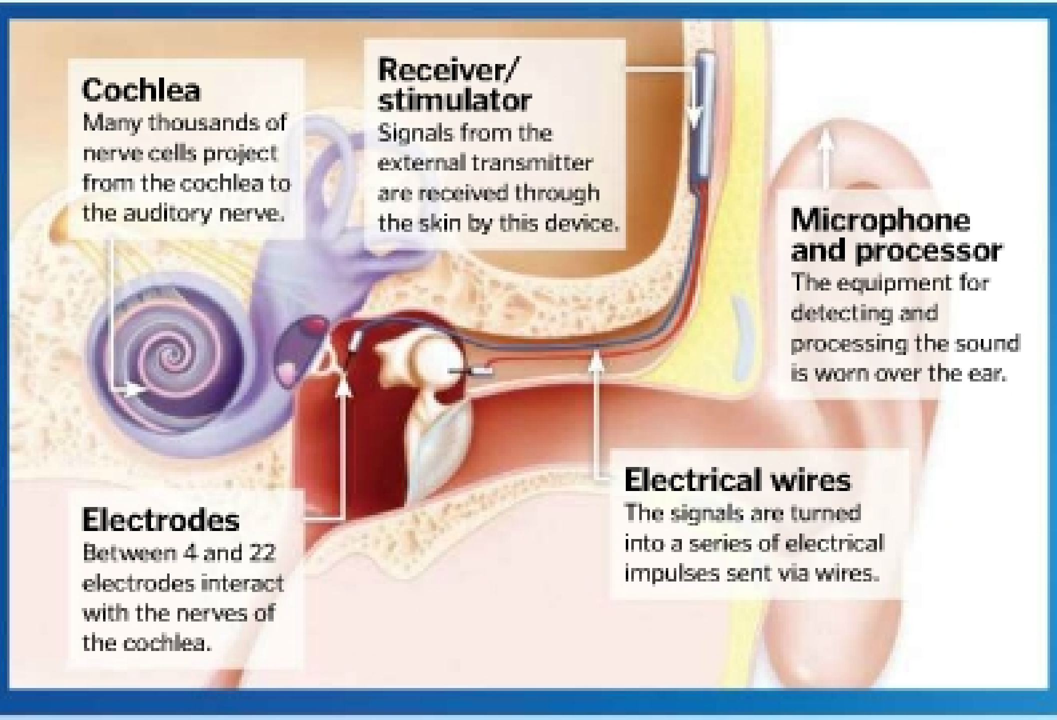
Implant
The implant transmits signals via 60 electrodes.

Rods and cones
Light detection by the eye's own cells is not necessary.

Ganglion cells
The long axons of these cells make up the optic nerve.

Cochlear implant

Nucleus 6, Cochlear
A cochlear implant has four main components. A microphone, worn near the ear, detects audio and transmits a signal to a sound processor. The processor then arranges the signal and sends it to a built-in transmitter. The transmitter passes the signal to an implanted receiver/stimulator, which transforms it into electrical stimuli for the electrodes. Finally these signals are relayed to the auditory nerve.



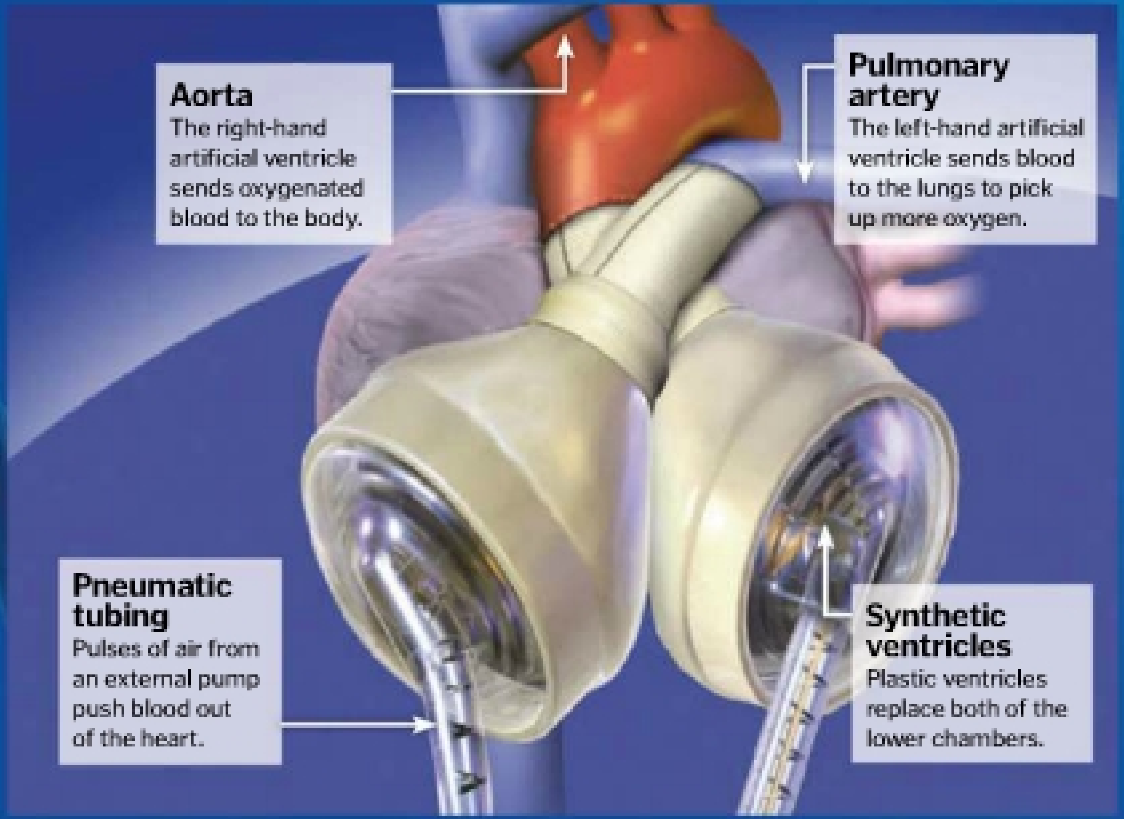
Cochlea
Many thousands of nerve cells project from the cochlea to the auditory nerve.

Receiver/stimulator
Signals from the external transmitter are received through the skin by this device.

Microphone and processor
The equipment for detecting and processing the sound is worn over the ear.

Electrical wires
The signals are turned into a series of electrical impulses sent via wires.

Electrodes
Between 4 and 22 electrodes interact with the nerves of the cochlea.



Aorta
The right-hand artificial ventricle sends oxygenated blood to the body.

Pulmonary artery
The left-hand artificial ventricle sends blood to the lungs to pick up more oxygen.

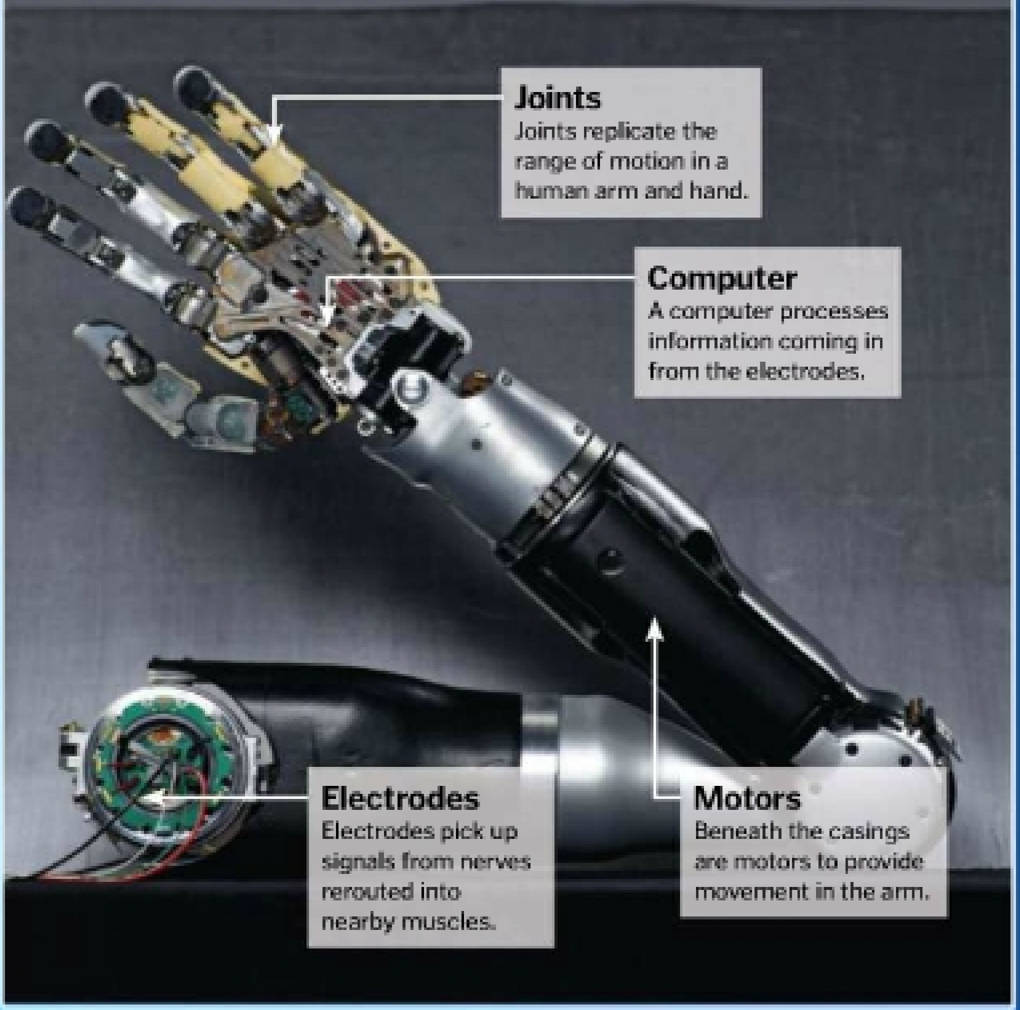
Pneumatic tubing
Pulses of air from an external pump push blood out of the heart.

Synthetic ventricles
Plastic ventricles replace both of the lower chambers.

Artificial heart

Total Artificial Heart, SynCardia Systems
Plastic hearts can be implanted to replace the two ventricles of the heart. Plastic tubing is inserted to replace the valves, and two artificial chambers are also attached. The heart is then connected to a pneumatic pump worn in a backpack, which sends bursts of air to the chambers, generating the pressure that's required to pump blood around the body.

Bionic arm



Joints
Joints replicate the range of motion in a human arm and hand.

Computer
A computer processes information coming in from the electrodes.

Electrodes
Electrodes pick up signals from nerves rerouted into nearby muscles.

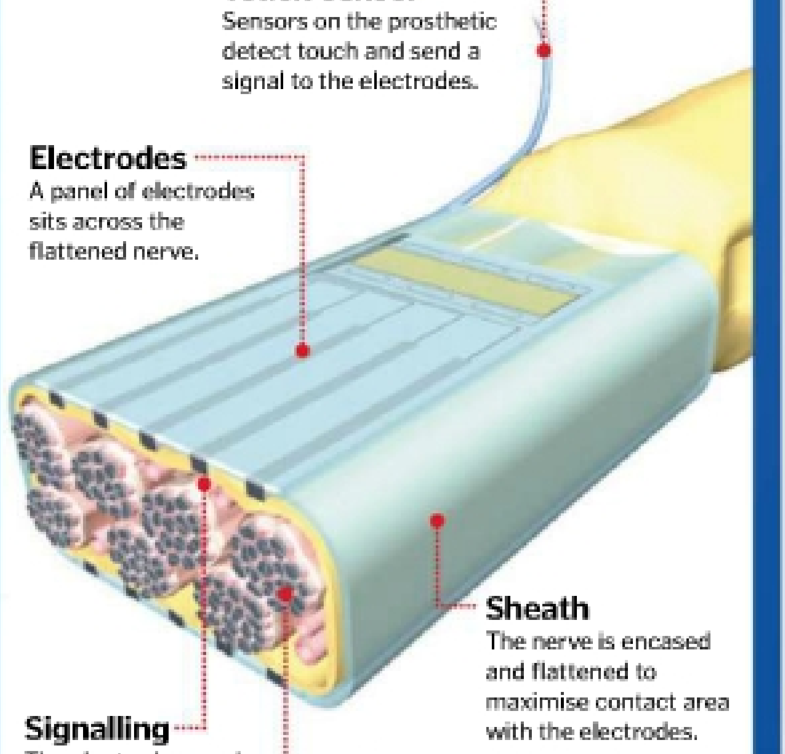
Motors
Beneath the casings are motors to provide movement in the arm.

Bionic limbs

Prosthetic limbs have come on leaps and bounds in the past couple of decades. They still retain characteristic features, such as an internal skeleton for structural support and a socket to attach to the amputation site, however the most innovative models are now able to reproduce, or even exceed, biological movements. Motors are used in place of muscles, springs instead of tendons and wires instead of nerves.

The movement of many prosthetics is controlled externally, using cables attached to other parts of the body, or using a series of buttons and switches. New technology is emerging to allow the user to move the limb using their mind (see 'The power of thought'). The next logical step in this process is developing technology that enables the prosthetic limb to sense touch, and relay the information back to the user. DARPA-funded researchers have developed FINE, a flat interface nerve electrode (see below left) which brings nerves into close contact with electrodes, allowing sensory data to pass to the brain.

Touch-sensitive prosthetics



Touch sensor
Sensors on the prosthetic detect touch and send a signal to the electrodes.

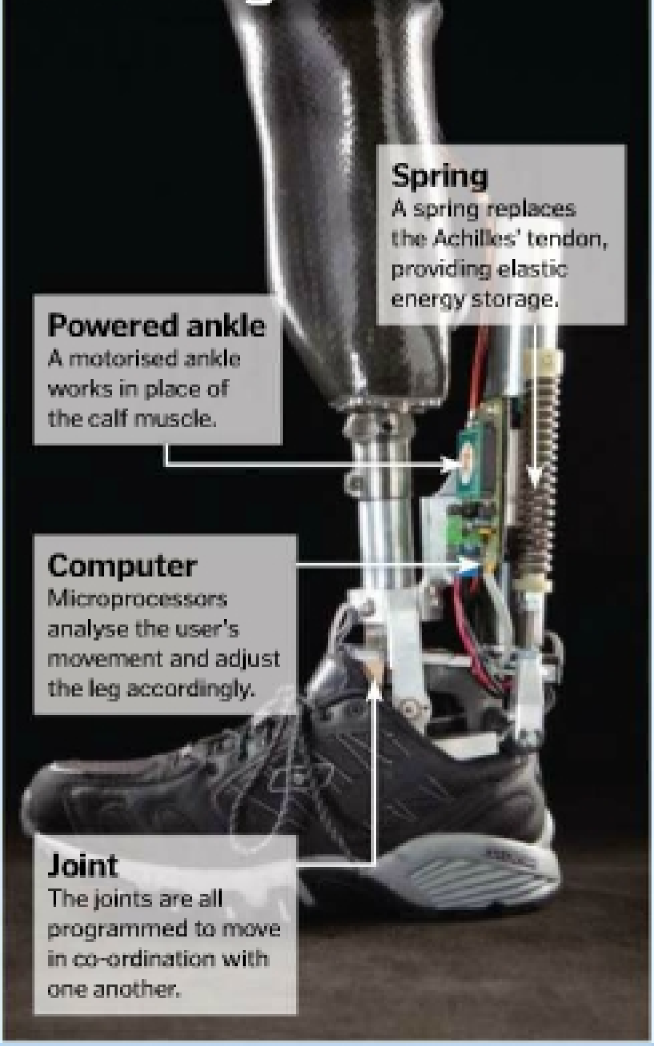
Electrodes
A panel of electrodes sits across the flattened nerve.

Sheath
The nerve is encased and flattened to maximise contact area with the electrodes.

Signalling
The electrodes send a small electrical signal to the nerve, causing it to fire.

Nerve
Sensory nerves transmit incoming signals to the brain.

Bionic leg



Spring
A spring replaces the Achilles' tendon, providing elastic energy storage.

Powered ankle
A motorised ankle works in place of the calf muscle.

Computer
Microprocessors analyse the user's movement and adjust the leg accordingly.

Joint
The joints are all programmed to move in co-ordination with one another.

The future of bionics

1 3D-printed organs
3D printing is the future of manufacturing and biologists are adapting the technology in order to print using living human cells. The cells are laid down in alternating layers alongside a transparent gel-like scaffold material. As the cells fuse, the scaffold disappears.

2 Ekso skeleton
Ekso Bionics has made bionic exoskeletons to allow people with lower limb paralysis to walk. Ekso supports their body and uses motion sensors to monitor gestures and then translate them into movement.

3 Artificial kidney
The University of California, San Francisco, is developing a bionic kidney. At about the size of a baseball, it contains silicone screens with nano-drilled holes to filter blood as it passes. It will also contain a population of engineered kidney cells.

4 Man-made immunity
Leuko-polymersomes are plastic 'smart particles' that mimic cells of the immune system. They are being designed to stick to inflammatory markers in the body and could be used to target drug delivery to infections and cancer.

5 Robotic blood cells
The Institute for Molecular Manufacturing is developing nanotechnology that could increase the oxygen-carrying capacity of blood. Known as respirocytes, the cells are made atom by atom – mostly from carbon.

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HEAD2HEAD
TAKING DRUGS

1. GOOD

Dry powder inhaler
This inhaler delivers medicine in a powdered form but the patient must do all the work to get the powder into their lungs.

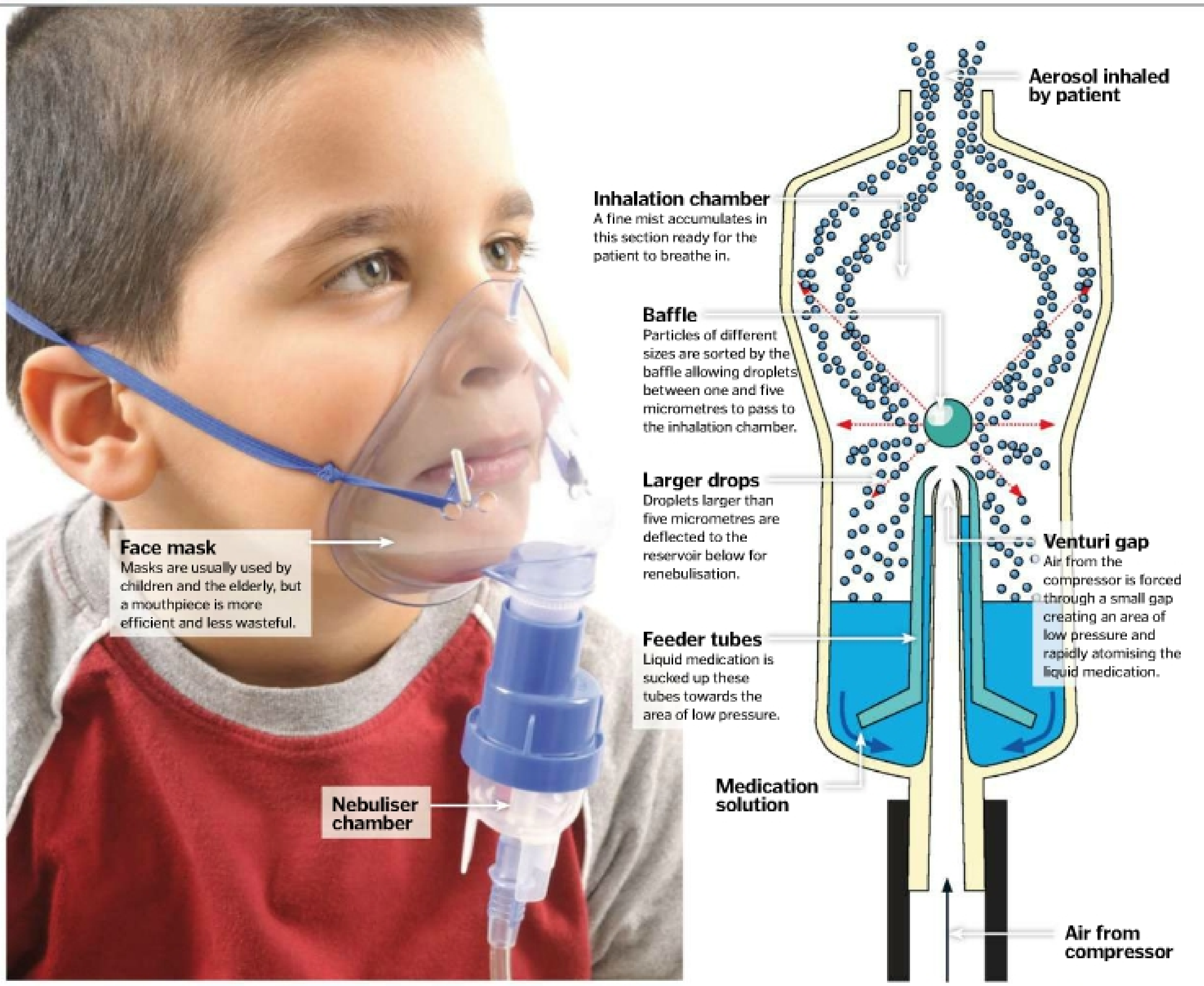
2. BETTER

Nebuliser
Straightforward to use but can be noisy during operation. Some medicine inevitably gets lost to the surroundings too making dosing unpredictable.

3. BEST

Metered dose inhaler
Giving an accurately measured dose and very portable these can be inhaled at any pace, so are suitable for all age groups.

DID YOU KNOW? *In most nebulisers, 80 per cent of the medication atomises within the first five minutes*


Aerosol inhaled by patient

Inhalation chamber
A fine mist accumulates in this section ready for the patient to breathe in.

Baffle
Particles of different sizes are sorted by the baffle allowing droplets between one and five micrometres to pass to the inhalation chamber.

Larger drops
Droplets larger than five micrometres are deflected to the reservoir below for renebulisation.

Venturi gap
Air from the compressor is forced through a small gap creating an area of low pressure and rapidly atomising the liquid medication.

Face mask
Masks are usually used by children and the elderly, but a mouthpiece is more efficient and less wasteful.

Feeder tubes
Liquid medication is sucked up these tubes towards the area of low pressure.

Nebuliser chamber

Medication solution

Air from compressor

Nebulisers demystified

How do these devices vaporise medication to treat respiratory problems?

For some treatments swallowing a pill or having an injection won't get to the root of the problem. Nebulisers offer an effective way to administer drugs directly to the lungs by vaporising a liquid solution of the drug into a fine mist of airborne liquid particles one to five micrometres in diameter. Primarily used to treat lung conditions such as chronic obstructive pulmonary disease, asthma and cystic fibrosis, the mist is inhaled allowing the drugs easier targeting of problem areas.

Jet nebulisers use an electric pump to force compressed air through a tiny gap – the Venturi. Here an area of low pressure forms due to the Bernoulli principle, which states that a stream of faster moving air will always have a lower pressure. A liquid solution of medicine is sucked up into small feeding tubes by this pressure difference where it meets the fast stream of air and atomises into an aerosol mixture of tiny liquid drops and air. The patient inhales this mixture through a mouthpiece or mask, holding their breath for a few seconds, which deposits the fine particles in the lungs instead of them being immediately exhaled.

Baffles inside the medicine container control particle size, trapping any droplets that are too big and directing them back towards the reservoir for renebulisation. Particles larger than five micrometres are unlikely to get as far as the lungs before depositing, while those finer than one micrometre tend not to deposit at all, as they're so light, and are exhaled.

© Thinkstock

> "Along with the Snapdragon S4 Pro system-on-a-chip, [it] is also fitted with an inductive charging coil"

HEAD 2 HEAD
TABLET WARS

1. GREAT

iPad mini
With a 1,024 x 768px, 20-centimetre (7.9-inch) display, a 1GHz dual-core CPU and 512MB of RAM, Apple's pint-sized iPad delivers decent specs.

2. GREATER

Galaxy Note 8.0
Offering a 1,280 x 800px, 20.3-centimetre (eight-inch) TFT screen, a 1.6GHz quad-core CPU and 2GB of RAM, the Galaxy Note 8.0 has solid all-round hardware.

3. GREATEST

New Nexus 7
With a 1,920 x 1,200px IPS screen, a 1.5GHz quad-core CPU and 2GB of RAM, the latest Nexus 7 is the most hi-def seven-inch tablet ever.

DID YOU KNOW? *The new Nexus 7 is said to offer up to nine hours of video playback or ten hours of web browsing*

Inside the new Nexus 7

Google's latest Nexus 7 has the most detailed screen ever created for a tablet – and it comes with a bevy of other advanced technology too

The new Nexus 7, the second generation of the Google-made tablet, is a 17.8-centimetre (seven-inch) device which currently can boast the highest-resolution tablet screen of its size in the world.

This record comes courtesy of the 323-pixel-per-inch (ppi) panel display, which is unsurpassed in any other tablet on the market – and that includes Google's own larger Nexus 10, which clocks in at only 300 ppi.

It's not just a one-trick pony though. In addition to the Nexus 7's record-breaking screen is a host of other cutting-edge hardware. Along with the impressive specifications delivered by the tablet's Snapdragon S4 Pro system-on-a-chip, the new Nexus 7 is also fitted with an inductive charging coil. This coil is designed to work with the Qi wireless interface standard and, partnered with a compatible charging device, allows the tablet to be topped up wirelessly by electromagnetic induction, bolstering a growing range of products doing away with traditional wired chargers.

In terms of software, the new Nexus 7 comes pre-installed with the latest Android operating system: 4.3 Jelly Bean. In terms of connectivity Wi-Fi, Bluetooth, NFC and LTE are all supported – the latter broadly so with seven LTE data frequencies enabled in both North America and Europe; a feat that no other tablet can lay claim to. A broad range of frequencies means that the one device can be used in conjunction with a variety of network suppliers, such as AT&T and Verizon in the US and Vodafone and Orange in the UK, rather than requiring individual network-specific models. ⚙

Why does ppi matter?

Arguably the most advanced piece of technology on the new Nexus 7 is the 323 ppi screen. This is a vast improvement on the original, which featured only 216 ppi. It's also a world record for a 17.8-centimetre (seven-inch) tablet.

The greater number of pixels you can squeeze into an inch of a device's panel, the higher the panel's overall resolution will be. As such, screens with high ppi counts are capable of displaying media with superior fidelity (ie crispness and detail) than those with lower counts. Typically high ppi screens are therefore associated with expensive, larger panels, such as those used in hi-def computer monitors.

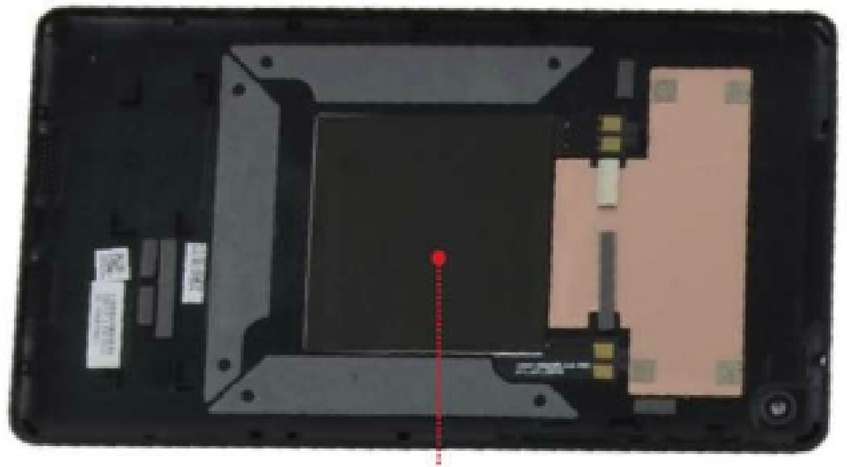
Importantly though, having a physically large screen does not in itself require a high ppi count, with many larger (and cheaper) panels delivering low ppi counts and poor fidelity. To find such a small screen with such a high ppi count in the Nexus 7 is something of a technological leap.

Learn more

In this issue's Group Test, we pit three of the latest tablets head to head, including the second-gen Nexus 7. See which comes out on top on page 88.

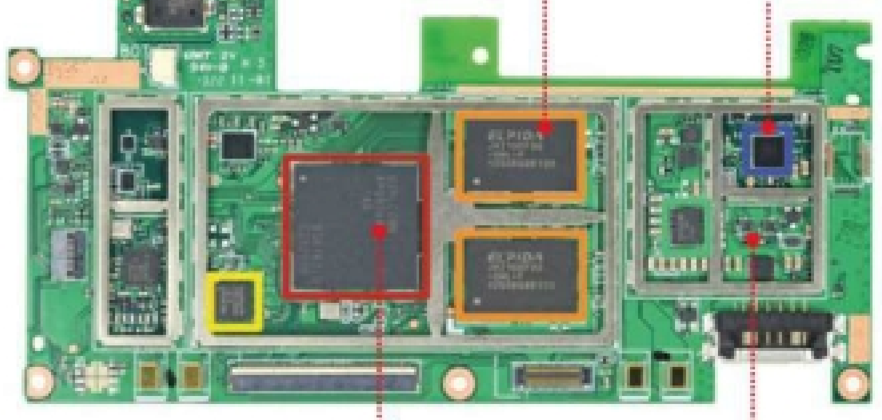
Nexus 7 teardown

We identify the next-gen tech powering this hot new tab



Inductive charging coil
A built-in inductive charging coil means the tablet can now be recharged wirelessly.

Casing
A purely plastic case contributes to its weight reduction from the original. It has a matte finish on the rear to help with grip.

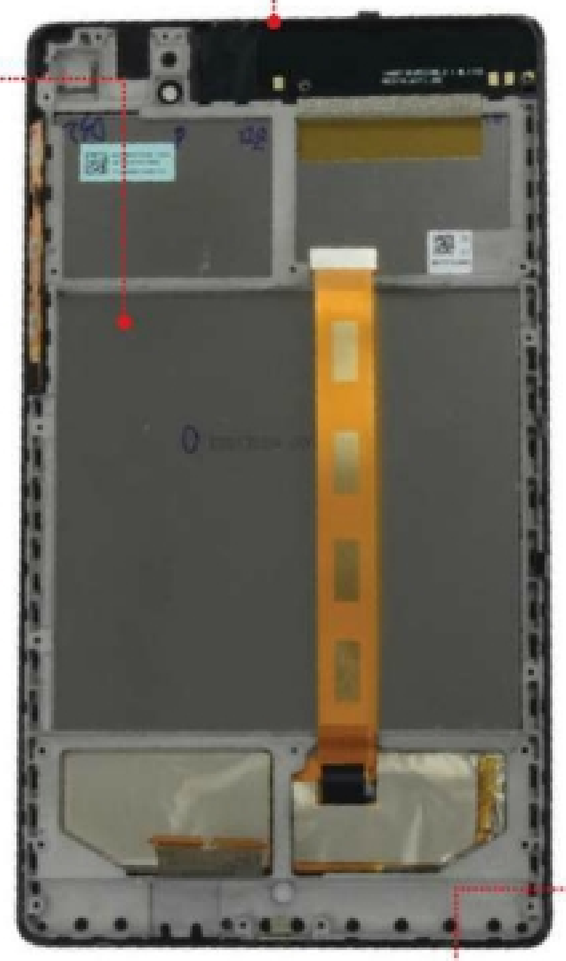


Elpida RAM
2GB of RAM comes in the shape of four 512MB DDR3L chips.

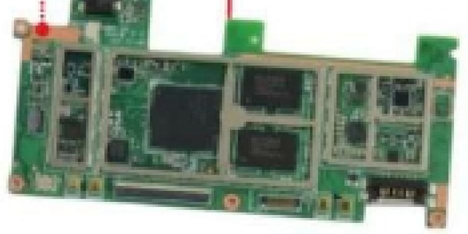
Qualcomm Atheros
This chip is responsible for controlling the tablet's WLAN a/b/g/n, Bluetooth 4.0 and FM radio functionality.

Qualcomm Snapdragon S4 Pro
The Nexus 7's system-on-a-chip contains its 1.5GHz quad-core CPU and Adreno 320 GPU.

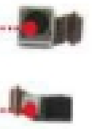
SK Hynix NAND Flash
Storage comes as a single chip of 16GB eMMC solid-state memory.



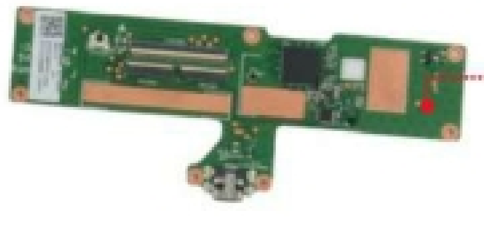
Screen
The new tablet's screen is a 1,920 x 1,200px IPS LCD panel with a pixel density of 323 ppi.



Motherboard
The motherboard contains a variety of key hardware (explored in detail above).



Cameras
There's a 5MP, autofocus rear camera and a 1.2MP front-facing camera.



Daughterboard
A secondary circuit board holds the tablet's capacitive touchpad controller – an ELAN integrated circuit.

Speakers
A brace of thin, plastic-composite speakers are installed in the top and bottom of the Nexus 7's case.

Battery
The 3,950mAh battery is rated at 3.8V and 15Wh; it offers an extra hour of usage over the original.

The new Nexus 7 is not only thinner and lighter than the original but faster too

The statistics...

Nexus 7 [second gen]

Height: 200mm (7.9in)
Width: 114mm (4.5in)
Depth: 8.7mm (0.3in)
Weight: 290g (10.2oz)
Screen size: 178.3mm (7in)
Screen resolution: 1,920 x 1,200px (323 ppi)
Battery: 3,950mAh
Storage: 16/32GB
Rear camera: 5MP
Front camera: 1.2MP
CPU: 1.5GHz quad-core Krait
GPU: Adreno 320
RAM: 2GB
OS: Android 4.3 Jelly Bean

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THE STATS
XPERIA Z ULTRA

DIMENSIONS 179x92x6.5mm CPU 2.2GHz quad-core
WEIGHT **212g** DISPLAY 1,920x1,080px BATTERY **3,000mAh**

DID YOU KNOW? *The first commercial waterproof mobile phone was the LG CanU 502S released in 2005*

Waterproof smartphones

How do these electronic devices carry on working even when underwater?

Today there are two main methods for waterproofing a smartphone: physical barriers such as port covers and sealed seams that prevent liquid entering externally, and nanocoatings that penetrate the device entirely and actively repel water. While both techniques are used, the most effective is the latter, enabling devices to be water resistant without compromising on size and aesthetics.

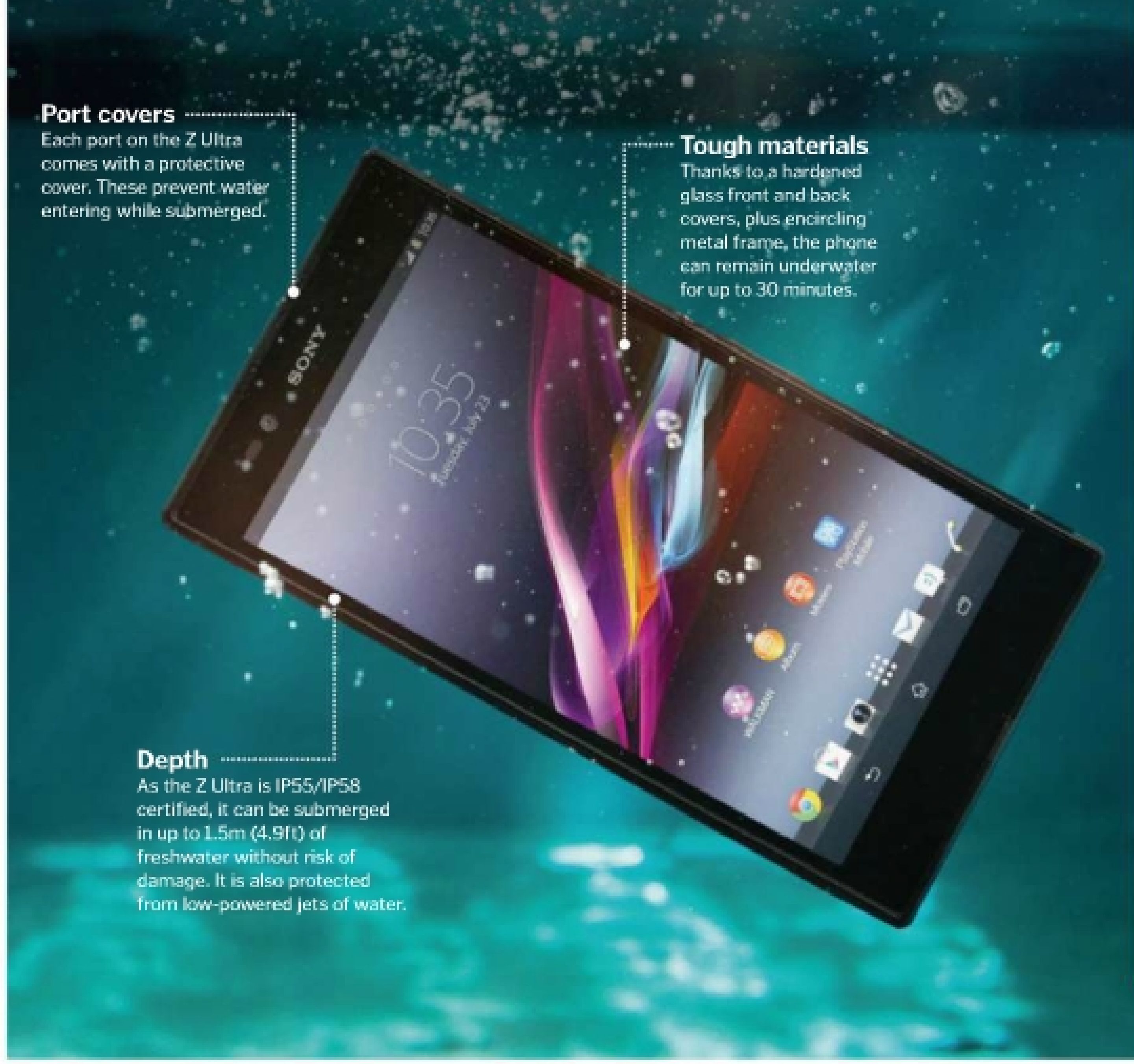
There are different types of nanocoating, but one of the most commonly used is that made by P2i. This company's waterproofing process involves subjecting any electronic gizmo to a plasma-enhanced vapour in a vacuum chamber at room temperature. The vapour contains a gaseous polymer, which when brought into contact with the device's surfaces – both external and internal – forms a super-strong covalent bond and waterproof barrier 1,000 times thinner than a human hair.

Once on the phone, the ultra-thin polymer layer then dramatically reduces its surface energy, forcing any water that comes into contact with it to bead up and be repelled.

Simply put, the coating acts in a similar way to the waxy feathers on a duck's back, preventing water from infiltrating the top layer and forcing it to run off the sides. Obviously, in the case of a smartphone, this action would prevent water from penetrating the delicate internal components. However, due to the vapour disposition process, even if water were to penetrate the mobile's casing, each internal component would also be coated with the polymer, protecting them until the water evaporated or was dried off manually.

A phone worth splashing out on

We pick out the key components that keep the Xperia Z Ultra super-dry



Port covers
Each port on the Z Ultra comes with a protective cover. These prevent water entering while submerged.

Tough materials
Thanks to a hardened glass front and back covers, plus encircling metal frame, the phone can remain underwater for up to 30 minutes.

Depth
As the Z Ultra is IP55/IP58 certified, it can be submerged in up to 1.5m (4.9ft) of freshwater without risk of damage. It is also protected from low-powered jets of water.

Waterproof phone rivals

1 Motorola Defy

With a single-core 800MHz CPU, 512MB of RAM, a 1,540mAh battery and a small 9.4-centimetre (3.7-inch) screen, the Defy is very much an entry-level water-resistant phone.

2 Samsung Galaxy S4 Active

With a quad-core 1.9GHz Snapdragon CPU, 2GB of RAM and Android 4.2.2 installed, the S4 Active is a decent-spec, good all-round smartphone that can take the plunge.

3 Sony Xperia Z Ultra

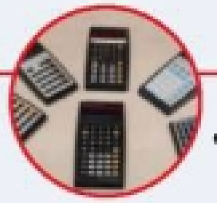
With a huge 16.3-centimetre (6.4-inch) screen, 2.2GHz quad-core CPU and 8MP camera, the Z Ultra is by far the largest and highest-spec waterproof phone on the market to date.

©Sony; Samsung; RobotBA

> "Using digital technologies with the internet, school is becoming a multimedia experience"

KEY DATES
PCs IN SCHOOL

1970s Pocket calculators become affordable, with many students starting to use them to help with sums.



1984 There's one computer for every 92 students in the US, such as early educational PCs like the Plato.

1991 The first interactive whiteboard is introduced by SMART; it takes several years to go mainstream.

2006 Cheap, durable laptops like the XO-1 are built so kids across the developing world have access to computers.

2010 Many schools begin using Apple iPads for educational games, video, apps and web browsing.

DID YOU KNOW? In English primary schools, there are currently around 1.8 students to every computer

Digital classrooms

From virtual lessons to interactive whiteboards, discover how new technology is revolutionising the way we learn

Technology is now at the heart of many classrooms, providing students with access to a whole new way of learning. Using digital technologies, combined with the internet, school is becoming a multimedia experience. Indeed, in 2012 there were 1.5 million iPads in use in education, as well as over 20,000 educational apps.

Of course, the internet has brought a huge resource to the digital classroom, granting instant access to a wealth of online information and educational tools. Many universities are uploading free materials to massive open online courses (or MOOCs) like iTunes U and Coursera, providing global access to free world-class education. Classrooms and labs are now also often equipped with microphones, speakers and webcams, opening up opportunities for collaborations across the globe.

Access to these digital educational resources is no longer limited to a single, rarely used computer in the corner; in fact, interactive whiteboards are now the focal point of many classrooms. A stylus, pen or finger is used to interact with a whiteboard, on which is projected an image of the computer screen. The user's movements are detected by the board and relayed back to the computer, allowing the user to write and draw on the screen (see 'Next-gen whiteboards' boxout for more detail).

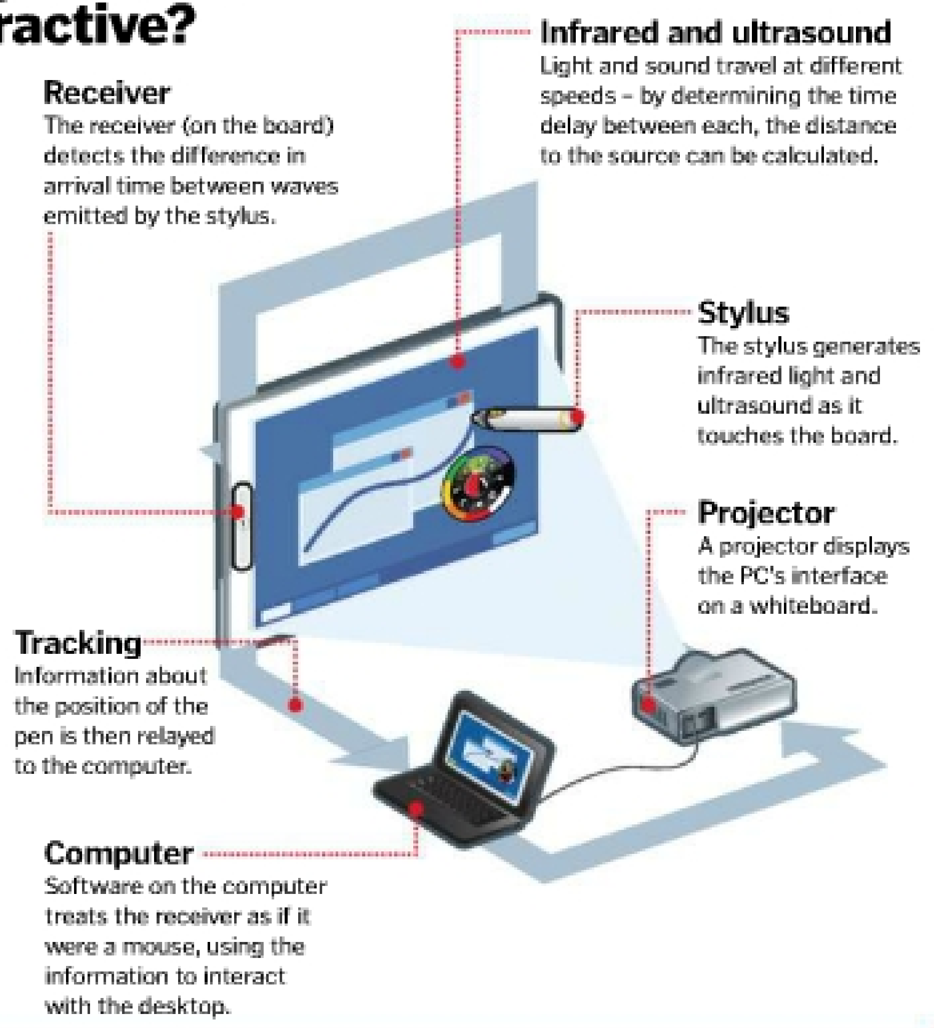
The interactive whiteboard is so much more than a digital chalkboard though. The pen-style interface means that many models come with bespoke software capable of handwriting recognition, converting everything that is written on the board into a digital archive. There are also programs available that allow anything drawn on the screen to be printed, recorded, shared and rewatched later. This has opened up possibilities for remote learning, allowing students unable to attend the physical classroom to still participate virtually.

What technology makes a whiteboard interactive?

Interactive whiteboards use a variety of technologies to provide the interface between user and screen. Infrared whiteboards use infrared wavelengths directed across the surface of the board. When a pen touches the board, it interferes with the light, allowing the point of contact to be calculated. Similarly, ultrasound whiteboards use the deflection of ultrasound waves to detect a stylus's movements.

Some whiteboards, like the eBeam made by Luidia pictured here, do not actually need an electronic board at all, but use a detector which is mounted to the side of a traditional whiteboard.

The eBeam system actually combines both infrared and ultrasound. By using the two together, differences in the time taken for the waves of light and sound to travel across the board enable the location and direction of the pen to be pinpointed. This works in a similar way to predicting the distance of a storm based on the time delay between seeing the lightning strike and then hearing the thunder.



Receiver The receiver (on the board) detects the difference in arrival time between waves emitted by the stylus.

Infrared and ultrasound Light and sound travel at different speeds – by determining the time delay between each, the distance to the source can be calculated.

Stylus The stylus generates infrared light and ultrasound as it touches the board.

Projector A projector displays the PC's interface on a whiteboard.

Tracking Information about the position of the pen is then relayed to the computer.

Computer Software on the computer treats the receiver as if it were a mouse, using the information to interact with the desktop.

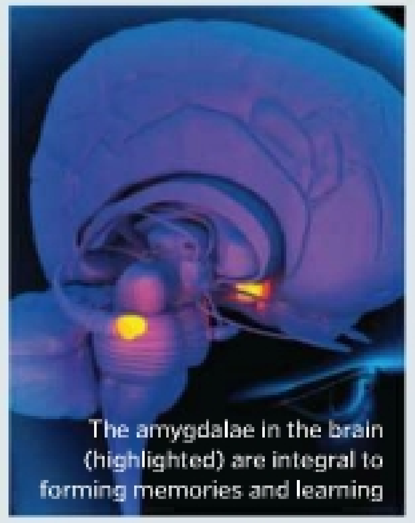
Dusty chalk and squeaky pens are now very much things of the past

How do we learn digitally?

As we learn, connections between neurons in the brain are reinforced; the more they are used, the stronger they become and the more easily we are able to recall the information.

Digital classrooms provide an engaging environment to reinforce memory. Different people find that they learn more easily in some ways than others – some preferring to watch, others preferring to interact, etc. Digital classrooms are able to offer tailored ways of learning, appealing to a wide range of preferences, and enabling classes to be adapted to individual students. One of the major advantages is that technology makes learning more fun, keeping pupils engaged for longer and providing memorable experiences to really help the knowledge stick.

One technique being increasingly employed to enhance learning through technology is 'gamification' – essentially turning learning into a game. The best educational games allow the student to learn without even realising it. Many of these games also include virtual rewards and leaderboards for an extra incentive.



The amygdalae in the brain (highlighted) are integral to forming memories and learning

© eBeam; SPL; Mike McGregor

THE STATS
JUPITER FIGURES

LENGTH OF YEAR 11.86 Earth years
LENGTH OF DAY 9.92 Earth hours
PERIHELION DISTANCE 741mn km
MASS 317.8 Earths
NUMBER OF MOONS 67

DID YOU KNOW? Since 1973 eight separate spacecraft have visited the Jovian system

JUICE Mission to Jupiter

Meet the ESA's new spacecraft that will explore the Solar System's biggest planet as well as its fascinating icy moons

Jupiter and its moons are part of a sort of 'mini Solar System', called the Jovian system that we still don't fully understand. Jupiter itself holds the record of being the largest planet in the Solar System, with storms the size of Earth and a unique atmosphere making it a world of great interest.

Orbiting Jupiter are dozens of natural satellites that are equally intriguing, with the four largest being the Galilean moons: Io, Europa, Ganymede and Callisto. Each of these is fascinating in its own right: Europa, for instance, is an icy moon with a possible saltwater ocean lurking beneath its surface, while Ganymede bears tantalising hints of a thin ozone layer not too dissimilar to Earth's.

With all that in mind, Jupiter has been the focus of several exploratory missions over the past few decades, from passers-by like the Voyager spacecraft to the Galileo orbiter that remained in the system from 1995 to 2003. Now, however, a new breed of spacecraft is on its way to study the Jovian system like never before. Already en route is NASA's solar-powered Juno probe, which will arrive in July 2016, and by 2030 the European Space Agency (ESA) will hopefully have its own spacecraft in orbit around the gas giant, called the Jupiter Icy Moons Explorer, or JUICE for short. ▶

> *"Europa is an icy moon with a possible saltwater ocean beneath its surface, while Ganymede bears hints of a thin ozone"*

Where it will launch...

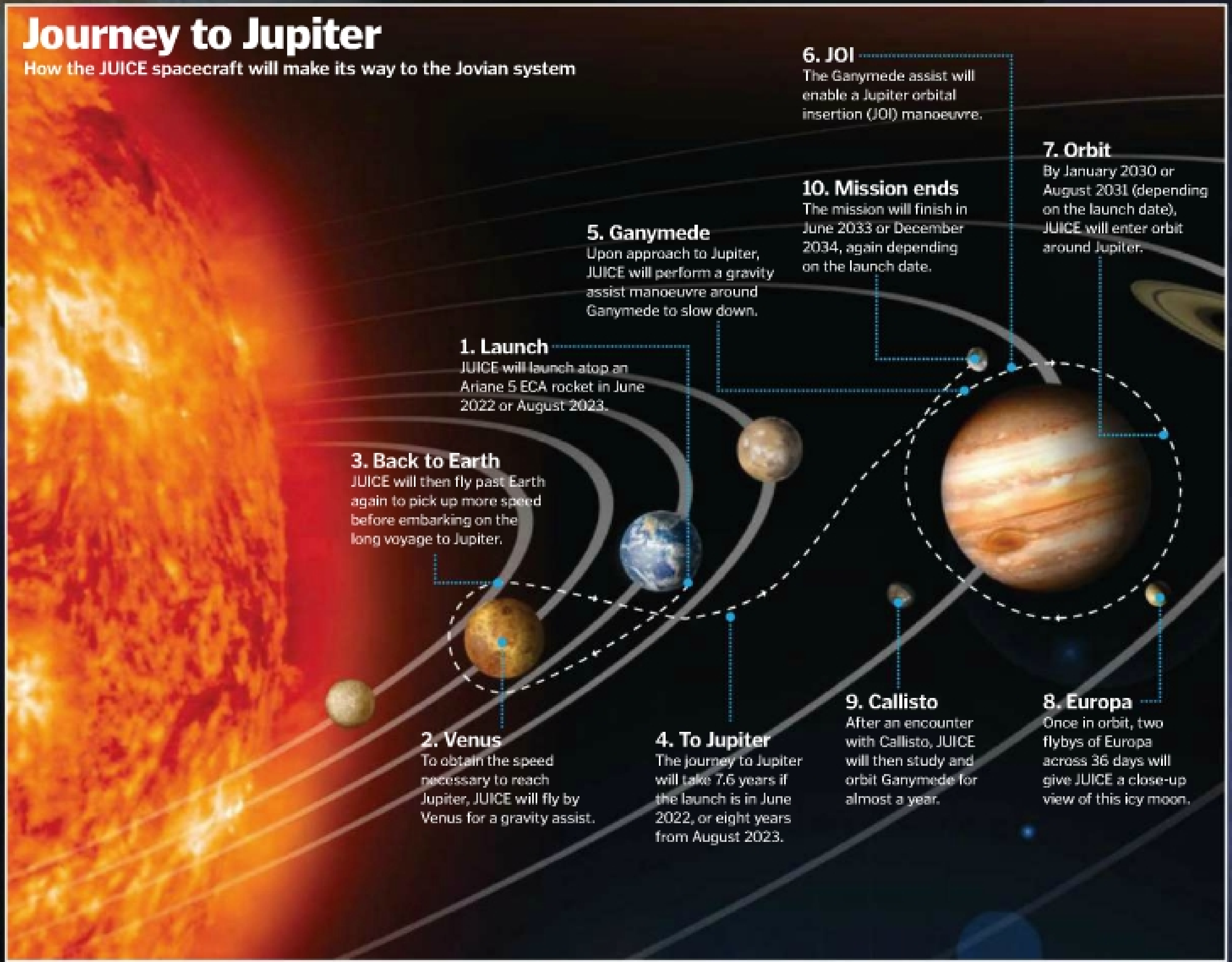
ESA, CNES (the French space agency) and the private company Arianespace conduct many of their rocket launches from the Guiana Space Centre, a spaceport located near Kourou in French Guiana that has been operational since 1968. Notable launches from here include the Herschel space telescope and the Galileo satellites used for global positioning.

The Guiana Space Centre is a prime launch site for two main reasons. The first is that it is located close to the equator, which means that rockets get an extra speed boost from the rotation of the Earth that they wouldn't get at more northern or southern latitudes. Its second advantage is that it is located in a sparsely populated area. Rockets launch over the Atlantic Ocean, so if for some reason one were to fail it would safely fall into the ocean and not threaten any built-up areas.

ESA's Herschel space telescope was launched on an Ariane 5 rocket from the Guiana Space Centre on 14 May 2009

Journey to Jupiter

How the JUICE spacecraft will make its way to the Jovian system



1. Launch
JUICE will launch atop an Ariane 5 ECA rocket in June 2022 or August 2023.

2. Venus
To obtain the speed necessary to reach Jupiter, JUICE will fly by Venus for a gravity assist.

3. Back to Earth
JUICE will then fly past Earth again to pick up more speed before embarking on the long voyage to Jupiter.

4. To Jupiter
The journey to Jupiter will take 7.6 years if the launch is in June 2022, or eight years from August 2023.

5. Ganymede
Upon approach to Jupiter, JUICE will perform a gravity assist manoeuvre around Ganymede to slow down.

6. JOI
The Ganymede assist will enable a Jupiter orbital insertion (JOI) manoeuvre.

7. Orbit
By January 2030 or August 2031 (depending on the launch date), JUICE will enter orbit around Jupiter.

8. Europa
Once in orbit, two flybys of Europa across 36 days will give JUICE a close-up view of this icy moon.

9. Callisto
After an encounter with Callisto, JUICE will then study and orbit Ganymede for almost a year.

10. Mission ends
The mission will finish in June 2033 or December 2034, again depending on the launch date.

> "This spacecraft will take with it a host of scientific instruments to study the Jovian system like never before"

KEY DATES
EXPLORING JUPITER

1973 Pioneer 10 becomes the first spacecraft to visit Jupiter when it flies past the gas giant in late-1973.

1979 Voyager 1 makes its closest approach to Jupiter, imaging the planet and some of its moons.

1995 The Galileo orbiter becomes the first spacecraft to orbit Jupiter and operates until 21 September 2003.

2000 On its way to Saturn the Cassini probe flies past Jupiter and takes about 26,000 images.

2016 NASA's solar-powered Juno probe is expected to enter orbit around Jupiter in July 2016.

DID YOU KNOW? Ganymede is the ninth-largest body in the Solar System – it's even bigger than Mercury!

▶ The focus of JUICE's mission, which will cost around €1 billion (£860 million/$1.3 billion), will be to examine and characterise three of the four Galilean moons – namely Europa, Ganymede and Callisto. This spacecraft will take with it a host of scientific instruments to study the Jovian system like never before, including high-resolution cameras and spectrometers to analyse the composition of Jupiter's atmosphere and its satellites. The emphasis of the scientific goals will be to provide evidence as to whether the moons – specifically Ganymede and Europa – could be habitable to some form of microbial life either on the surface or in the oceans thought to exist under each moon's icy crust.

The spacecraft will launch on an Ariane 5 rocket in June 2022 to make use of favourable positioning of Jupiter to enable the spacecraft to reach the planet by using gravitational assists from Venus and Earth. A secondary launch date of August 2023 has also been put in place, which means there's a backup if for some reason JUICE is delayed. The spacecraft is powered by a solar array, while multiple thrusters will enable it to orientate itself.

Once at the Jovian system JUICE will spend over three years studying Jupiter and its moons. Aside from the bodies mentioned earlier, the nature and longevity of the mission means that JUICE will be able to study many other interesting objects around Jupiter such as the volcanically active moon Io and some of the smaller natural satellites too.

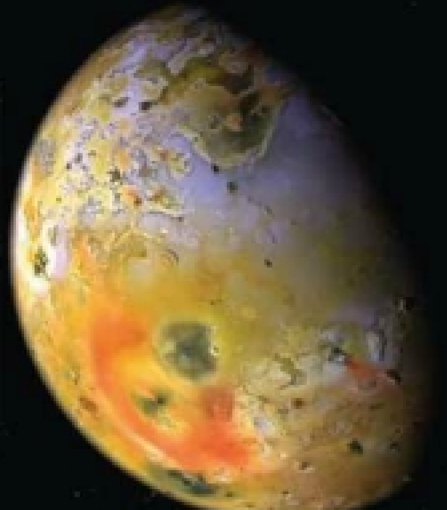
JUICE will carry 11 scientific experiments that each has a specific purpose. One of the most interesting is an ice-penetrating radar that, by using a method known as sounding, will be able to measure the thickness of the icy crust on moons such as Ganymede and Europa – something that has never been done before – and thus revealing the depth of any subsurface oceans. There's also a proposal to include a Russian-built Ganymede lander with JUICE, which could touch down on the moon and perform surface operations, although this has not been decided on yet.

JUICE is part of the European Space Agency's Cosmic Vision programme – the over-arching name that's been given to all ESA scientific space missions taking place between 2015 and 2025. Barring any problems or delays, JUICE will become one of the highest-profile missions in the Solar System when it launches in the early-2020s, so it's certainly one to watch out for. ✽

Science at Jupiter

JUICE's main objective is to study three of the Galilean moons – Ganymede, Europa and Callisto – with particular emphasis on the former. This will include performing a detailed characterisation of the moons and ascertaining whether they may be hospitable to life. JUICE will also study Jupiter and its atmosphere to help us further understand the gas giant planet.

Callisto
The desolate Callisto is one of the most heavily cratered bodies in the Solar System, but its ancient and inactive surface could hold some of the oldest records from the early Solar System. Callisto, like Ganymede and Europa, may also be concealing an ocean beneath its surface, so JUICE will conduct further studies of the moon to deduce whether or not this is the case by looking for subsurface water reservoirs. JUICE will attempt to map parts of the surface and pin down its physical properties as well.

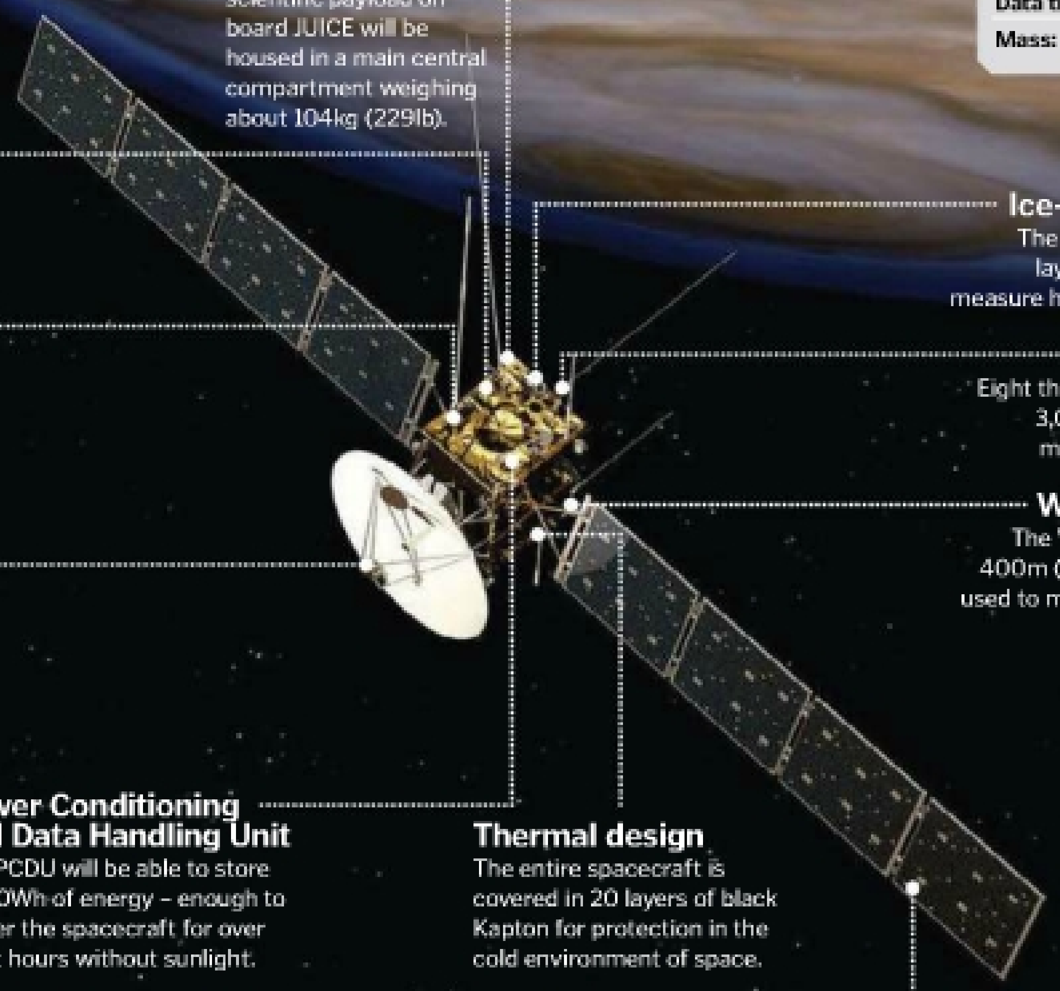


Io
While in the Jovian system JUICE may have a chance to observe the fascinating moon that is Io – the most volcanic place in the Solar System. It has more than 400 known active volcanoes that spew sulphur and other material onto its surface, lending the moon its odd yellow hue. Io's volcanism stems from its eccentric orbit around Jupiter, with the gas giant and its other moons pushing and pulling Io to cause extreme tidal heating at its core.

Ganymede
Ganymede is the largest moon in the Solar System, and also one of the most interesting. Like Europa it's believed to have an icy crust with a rocky surface lurking below, while it may also have a magnetic field like Earth's that interacts with the Jovian magnetosphere. JUICE will attempt to reveal more about Ganymede by performing topographical and geological mapping of the surface, in addition to characterising the icy surface and subsurface ocean with the various scientific instruments on board.

Europa
Europa is one of the most fascinating bodies in the Solar System, mainly because it has a smooth icy surface that may be hiding an ocean underground with more water than all that found on Earth. JUICE will scour Europa for signs of organic molecules and life-essential chemistry, in addition to learning more about its surface features, such as cracks and fissures. JUICE will also measure the minimal thickness of Europa's icy crust at some active regions that may be spewing up liquid water from below.

On board JUICE
We highlight the major instruments that this spacecraft will take with it



Payload
The majority of the scientific payload on board JUICE will be housed in a main central compartment weighing about 104kg (229lb).

Narrow-angle camera
The NAC will take high-resolution images of Jupiter and its moons, with resolutions of up to just a few metres per pixel.

VIRHIS
The Visible Infrared Hyperspectral Imaging Spectrometer will study the composition of the moons' surfaces and Jupiter's atmosphere.

Antenna
JUICE will communicate with the Earth using a high-gain antenna (HGA) 3.2m (10.5ft) wide.

Power Conditioning and Data Handling Unit
The PCDU will be able to store 4,750Wh of energy – enough to power the spacecraft for over eight hours without sunlight.

Thermal design
The entire spacecraft is covered in 20 layers of black Kapton for protection in the cold environment of space.

Ice-penetrating radar
The IPR will explore the inner layers of the icy moons and measure how thick their crusts are.

Propulsion
Eight thrusters are fed by almost 3,000kg (6,615lb) of fuel to manoeuvre the spacecraft.

Wide-angle camera
The WAC, with a resolution of 400m (1,300ft) per pixel, will be used to map Jupiter and its moons from afar.

Solar panels
Eight panels of equal size spanning 64m² (689ft²) house the solar cells that gather energy from the Sun.

The statistics...

JUICE mission

Launch date:
June 2022
(backup: August 2023)

Launch vehicle: Ariane 5 ECA

Mission duration: 11 years

Dimensions:
2.3 x 1.7 x 3.1m
(7.4 x 5.6 x 10.3ft)

Solar array area:
64m² (689ft²)

Data transfer: 1.4Gb per day

Mass: 4,800kg (10,582lb)

© NASA; ESA; Adrian Mann

> "In the case of human payloads, these were delivered via an airlock located at the front of the shuttle"

RECORD BREAKERS
EPIC DELIVERY

22,753kg

BIGGEST PAYLOAD TO SPACE
The heaviest non-commercial payload ever launched – the Chandra X-ray Observatory – weighed in at 22,753 kilograms (50,161 pounds) on Space Shuttle mission STS-93 in 1999.

DID YOU KNOW? The last Space Shuttle launch – STS-135 – carried a payload of 3,630kg (8,000lb) of supplies

Space Shuttle payload bay

How did this colossus deliver tons of supplies and technology into space?

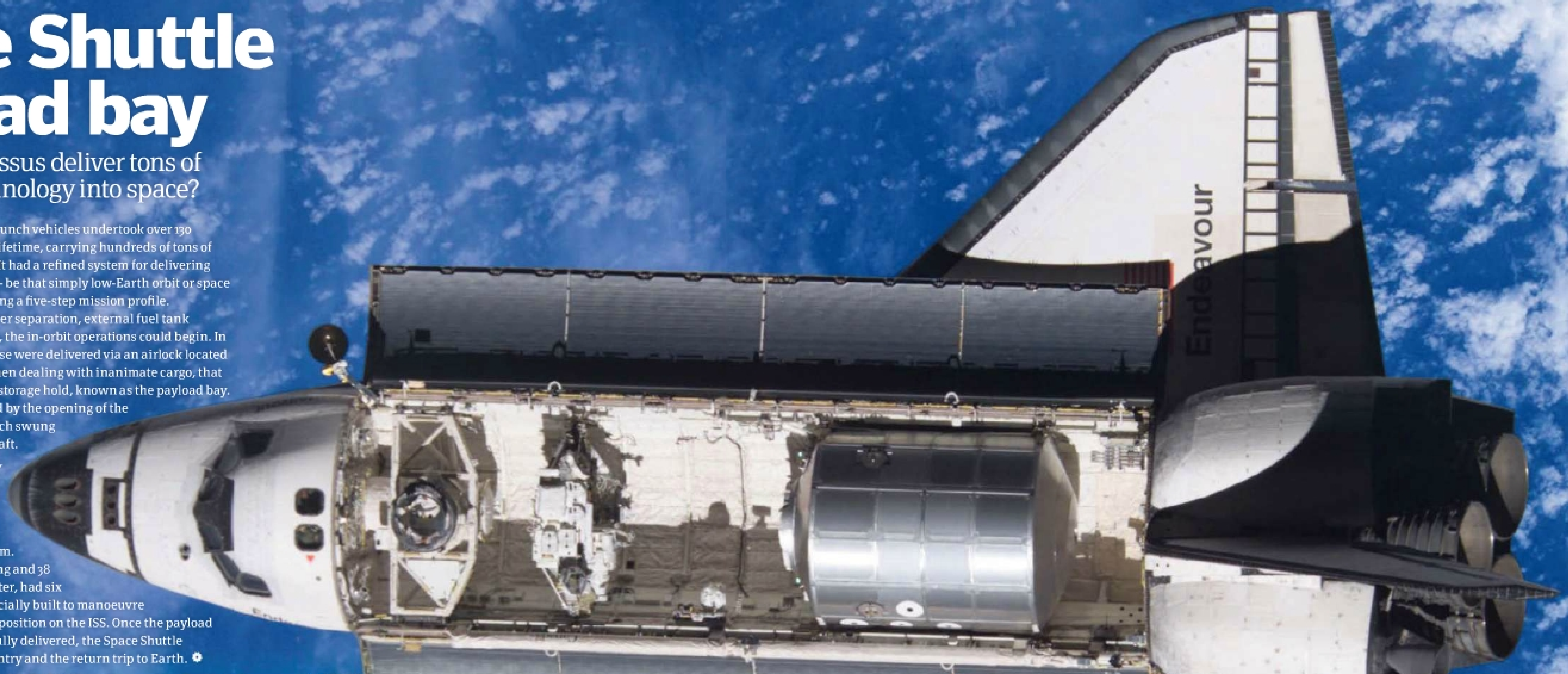
NASA's Space Shuttle launch vehicles undertook over 130 missions during their lifetime, carrying hundreds of tons of technology into space. It had a refined system for delivering payloads to the intended target – be that simply low-Earth orbit or space stations such as the ISS – following a five-step mission profile.

After liftoff, solid-rocket booster separation, external fuel tank separation and orbital insertion, the in-orbit operations could begin. In the case of human payloads, these were delivered via an airlock located at the front of the shuttle, but when dealing with inanimate cargo, that required accessing the internal storage hold, known as the payload bay. Tech and supplies were accessed by the opening of the shuttle's payload bay doors, which swung open from the top of the spacecraft.

Once the bay doors were open, the resources within could be collected either by an EVA (extravehicular activity, or spacewalk), or using a robotic mechanical arm called Canadarm. This arm, 15.2 metres (50 feet) long and 38 centimetres (15 inches) in diameter, had six degrees of freedom and was specially built to manoeuvre cargo from the bay to their final position on the ISS. Once the payload for a mission had been successfully delivered, the Space Shuttle would then be prepared for re-entry and the return trip to Earth. ✪

The STS-133 payload canister is lifted into the rotating service structure on Launch Pad 39A

The Canadarm being used to retrieve cargo from within the Space Shuttle



Endeavour in flight clearly showing its spacious payload bay on STS-111

© NASA

> "The density becomes so great that further fusion reactions release an immense amount of energy"

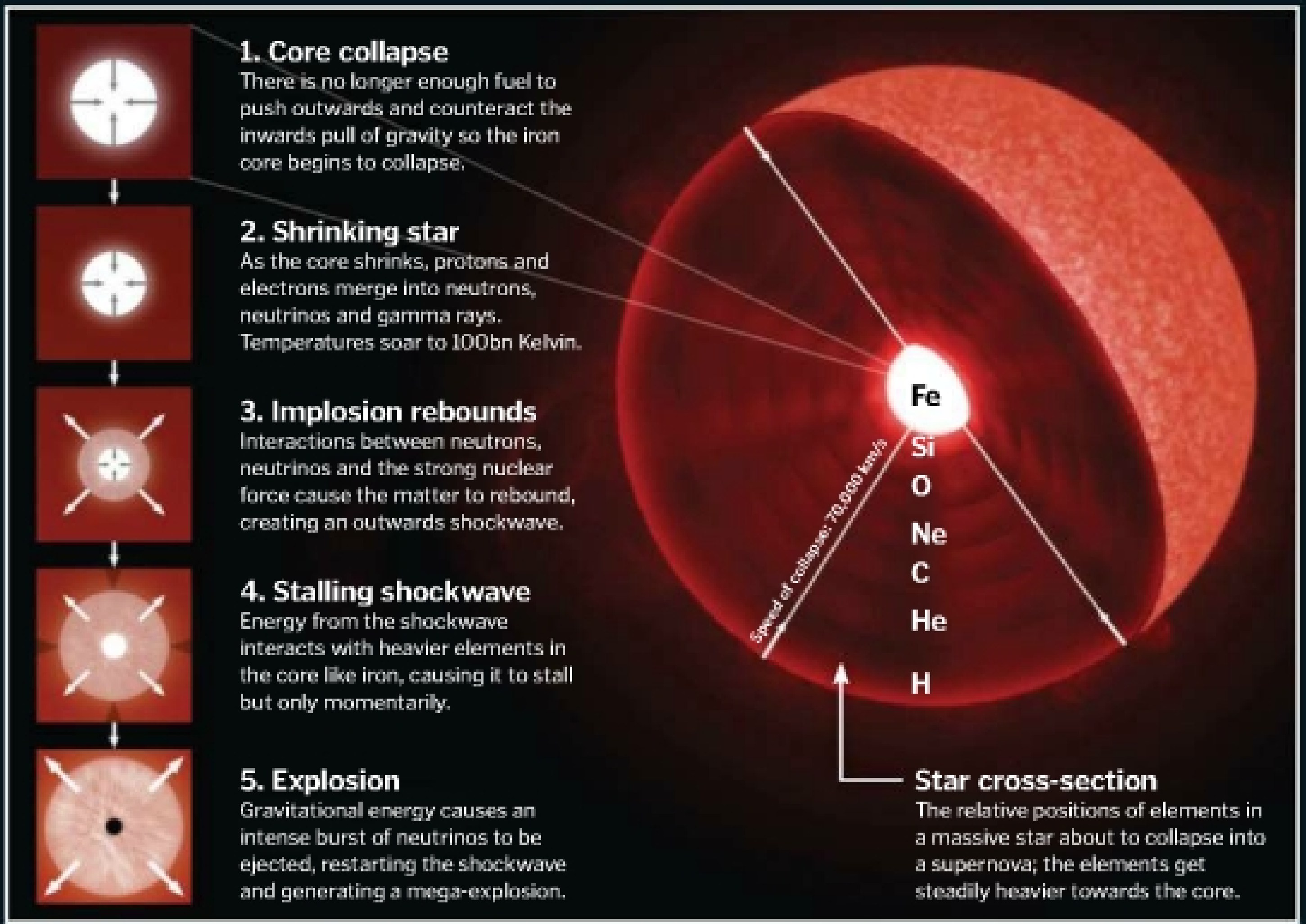
How huge stars go supernova

Key events at the end of a massive star's life that lead to a cataclysmic explosion

All stars are giant balls of gas trying to collapse under their own gravity. Pressure caused by the collapse generates nuclear fusion – the fusing together of hydrogen and helium nuclei – giving off enough energy to push outwards, so the star doesn't collapse further.

When massive stars eight times the mass of our Sun run low on fuel, the inwards pull of gravity overcomes this outward force, causing the star to shrink. The density becomes so great that further fusion reactions release an immense amount of energy in a matter of seconds, generating the most explosive event in the universe: a supernova.

A large proportion of the star's material is ejected outwards, while an inwards force of equal magnitude causes the remaining matter to collapse into a neutron star or even a black hole.



1. Core collapse
There is no longer enough fuel to push outwards and counteract the inwards pull of gravity so the iron core begins to collapse.

2. Shrinking star
As the core shrinks, protons and electrons merge into neutrons, neutrinos and gamma rays. Temperatures soar to 100bn Kelvin.

3. Implosion rebounds
Interactions between neutrons, neutrinos and the strong nuclear force cause the matter to rebound, creating an outwards shockwave.

4. Stalling shockwave
Energy from the shockwave interacts with heavier elements in the core like iron, causing it to stall but only momentarily.

5. Explosion
Gravitational energy causes an intense burst of neutrinos to be ejected, restarting the shockwave and generating a mega-explosion.

Star cross-section
The relative positions of elements in a massive star about to collapse into a supernova; the elements get steadily heavier towards the core.

Communicating with space probes

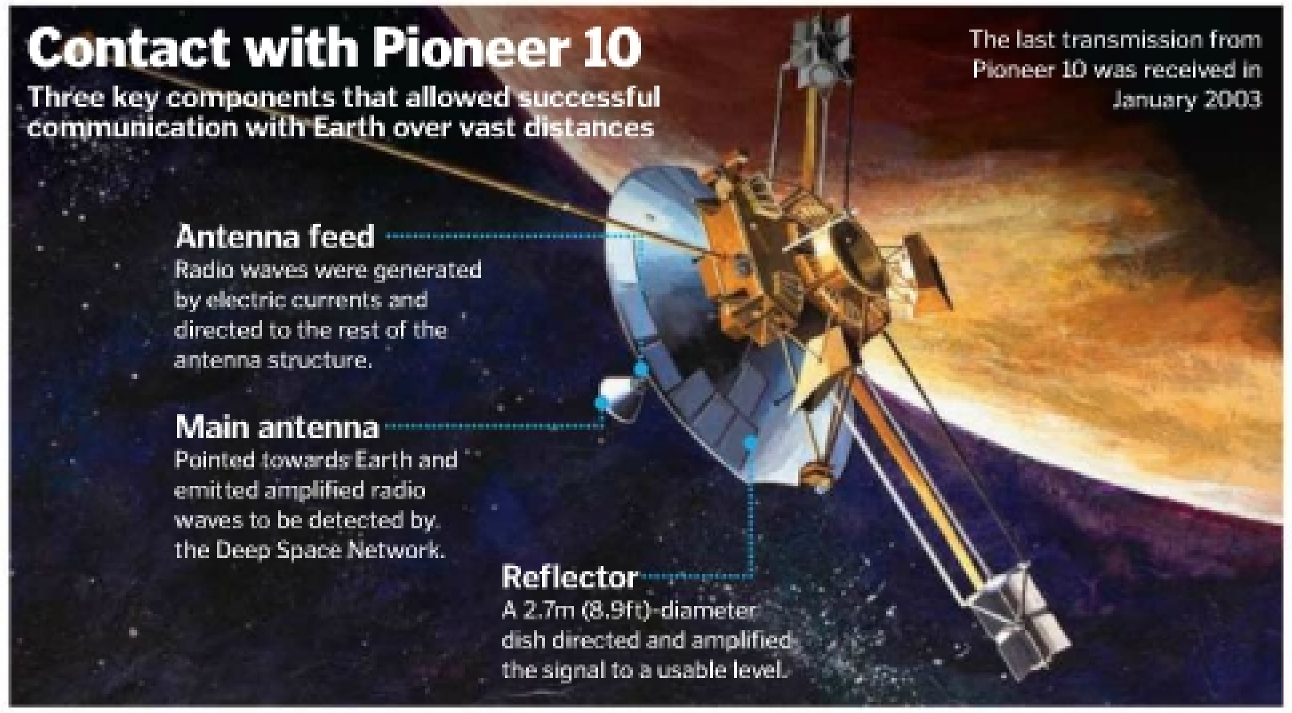
How do scientists keep in touch with deep-space probes like Pioneer 10 and 11?

Communicating with something over 11.2 billion kilometres (7 billion miles) away is no mean feat, and requires a worldwide network of huge radio antennas. Stations in California, Spain and Australia form the Deep Space Network (DSN) – strategically spread out to ensure there will always be one antenna that can point at any space probe.

Likewise, space probes – like Pioneer 10 and 11 launched in the early-Seventies – need antennas to send pictures, weather data and heading information as radio waves. However power constraints mean that space probes can only send very weak signals, which get weaker the farther away they travel. Antennas on the ground have large dishes to capture the signal, yet greater amplification and noise reduction is needed to boost the signal to a readable level.

Contact with Pioneer 10

Three key components that allowed successful communication with Earth over vast distances



The last transmission from Pioneer 10 was received in January 2003

Antenna feed
Radio waves were generated by electric currents and directed to the rest of the antenna structure.

Main antenna
Pointed towards Earth and emitted amplified radio waves to be detected by the Deep Space Network.

Reflector
A 2.7m (8.9ft)-diameter dish directed and amplified the signal to a usable level.

© Alamy; NASA

THE STATS
TRITON NUMBERS

DISCOVERED	1846
GRAVITY	$0.779m/s^2$
DIAMETER	2,700km
TEMPERATURE	38K
VOYAGER 2 VISIT	1989
ORBITAL PERIOD	5.87 days

DID YOU KNOW? Triton is so massive that if it were orbiting the Sun it would be considered a dwarf planet

The backwards moon

Why is Neptune's biggest satellite, Triton, the only large moon in the Solar System to orbit its planet in the opposite direction?

Moons usually orbit in the same direction as their parent planet is spinning. Triton's unique orbit indicates it was not formed in the same region as Neptune. Instead, it is believed that it was captured from the Kuiper Belt, an icy ring at the edges of the Solar System that contains thousands of bodies, including Pluto.

For an object to be captured by a planet, it must lose energy, preventing it from escaping the gravitational field. This often occurs as a result of a collision; however, in the case of Triton, this is thought to be unlikely. Instead, Triton may have originally had a companion, like Pluto's moon Charon. As the pair came close to Neptune, their orbital energies were disrupted, being transferred to Triton's companion and expelling it from the system, leaving Triton caught in Neptune's orbit.

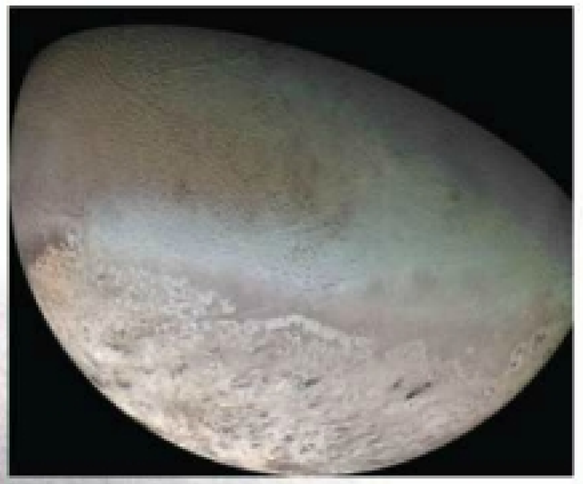
Triton is very similar in composition to Pluto; it has an icy surface primarily composed of frozen nitrogen, water and carbon dioxide. It is the seventh-largest moon in the Solar System, and is more massive than all of the smaller moons combined. Triton's surface shows evidence of having been melted, and icy volcanoes erupt from the crust, spewing gas and dust about eight kilometres (five miles) up.

Beneath the crust are a mantle of water and a core of rock and metal. It is possible that the heat generated by radioactive decay in the rocky core is able to keep the mantle molten, producing a liquid ocean below the moon's outer surface, similar to that on Europa.

Could you spend a day on Triton?

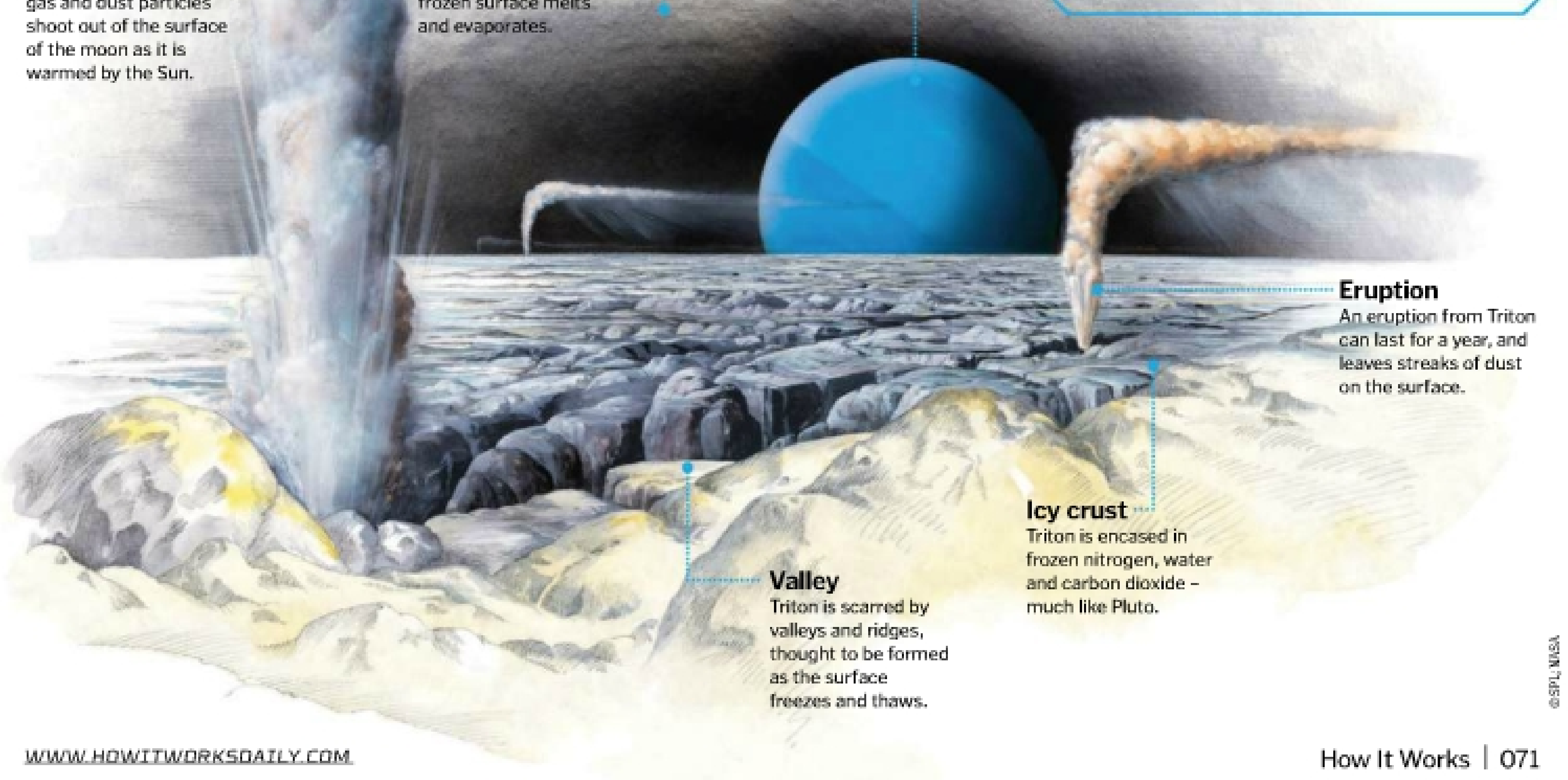
Despite the fact that Triton has a solid, icy surface, it would presently be impossible for a human to step onto the moon. Surface gravity is 12 times weaker than Earth's, and the average temperature is in the region of 38 degrees Kelvin (-235 degrees Celsius/-391 degrees Fahrenheit).

Equally problematic, Triton's atmosphere is very thin. It is composed of nitrogen gas, which is thought to have evaporated from the frozen nitrogen that covers the moon's surface. The atmosphere is so thin that atmospheric pressure is just one-70,000th what it is on Earth.



On the surface

If it were possible to visit Triton, this is what you might see…



Cryovolcano
Eruptions of nitrogen gas and dust particles shoot out of the surface of the moon as it is warmed by the Sun.

Nitrogen atmosphere
Triton's atmosphere is composed of nitrogen gas released as the frozen surface melts and evaporates.

Neptune
Triton orbits the gas planet Neptune along with 13 other satellites.

Eruption
An eruption from Triton can last for a year, and leaves streaks of dust on the surface.

Valley
Triton is scarred by valleys and ridges, thought to be formed as the surface freezes and thaws.

Icy crust
Triton is encased in frozen nitrogen, water and carbon dioxide – much like Pluto.

© SPL; NASA

Neil Armstrong

Discover how a boy with a fascination for aviation went on to be the first man to set foot on the Moon

> "Neil Armstrong earned his flight certificate by the age of 16 – before he had even learnt how to drive"

Neil Armstrong was 38 years old when he was chosen to lead Apollo 11

Armstrong's interest in flying began at a very early age. His father took him to the Cleveland Air Races at the age of two, and he flew in a Ford 'Tin Goose' aircraft at the age of six. As a schoolboy, he made model planes, collected books on aviation and even took odd jobs in order to fund flying lessons. He earned his flight certificate by the age of 16 – before he had even learnt how to drive.

His interest in flight led him to pursue a degree in Aeronautical Engineering at Purdue University, IN. He studied under a scholarship, which stipulated three years of service in the US Navy during his degree. Armstrong was called up in 1949, and underwent 18 months of flight training, and by his 20th birthday he was a qualified naval aviator.

From 1951, Armstrong saw action in the Korean War. He flew 78 missions over Korea, earning several medals for naval service. He left the US Navy after the war and returned to university to complete his degree.

After his graduation in 1955, Armstrong became a research test pilot, during which time he flew more than 200 different types of aircraft. His extensive flight experience saw him selected for the 'Man In Space Soonest' (MISS) programme with the US Air Force.

In 1966 Armstrong served as command pilot for the Gemini 8 mission – which was the first mission during which two vehicles docked in space – and just two years later, he was selected as the commander for the game-changing Apollo 11 mission heading to the Moon.

Having spent a year learning to pilot a modified version of the Lunar Module on Earth, he and two colleagues departed for the Moon on 16 July 1969. The Lunar Module landed on the surface of the Moon on 20 July and, at 10.56pm EDT, Neil Armstrong became the first man to set foot on an extraterrestrial body, uttering the famous words, "That's one small step for man, one giant leap for mankind". Buzz Aldrin followed him onto the surface 20 minutes later, and the pair then spent over two and a half hours conducting experiments and gathering samples. They also erected a plaque and planted a US flag to commemorate the mission.

On re-entering the Lunar Module, Armstrong discovered that the ignition switch had been broken by their spacesuits, and had to restart the craft using a pen to push the circuit breaker. After splashing down in the Pacific Ocean, the crew were quarantined for 21 days to safeguard against any infection that might have been contracted in space. They then spent 45 days on a tour of the world to celebrate one of mankind's greatest-ever achievements.

After the Apollo 11 mission, Armstrong retired from spaceflight and took a teaching position at the University of Cincinnati, OH. He continued to work for NASA as well though, and assisted in the investigations following the Apollo 13 and Challenger disasters.

Armstrong working on the Lunar Module on the surface of the Moon

Armstrong made a cast of his footprint for display at the Marshall Space Flight Center in 2007

The Apollo 11 crew; from left to right, Neil Armstrong, Michael Collins, Buzz Aldrin

In their footsteps...

Chris Hadfield

In March 2013, Chris Hadfield became the first Canadian commander of the ISS. Hadfield describes watching the lunar landing in 1969 as a "watershed moment" and admired Armstrong for his "quiet accomplishment". There was no space programme in Canada when Hadfield was a child, but Armstrong inspired him to pursue his dream.

Sally Ride

An inspiration herself, Sally Ride was the first US woman in space. In the early days of space travel, NASA recruited mostly military pilots for their missions, but as missions became ever-more advanced, the need to take scientists to space became apparent. Physicist Ride was recruited and flew two missions aboard Challenger.

The big idea

In 1969, Neil Armstrong was commander of a three-man mission to the Moon – Apollo 11. Armstrong's famous words, "That's one small step for man, one giant leap for mankind", were not planned until the Lunar Module had touched down. In interviews he later stated that he thought the chances of a successful touchdown were so small that planning what to say in advance was unnecessary.

Top 5 facts: Neil Armstrong

1 War hero While flying in the Korean War, Armstrong's F9F Panther was hit by anti-aircraft fire. He collided with a pole and part of the wing was ripped off, but luckily he wasn't injured.

2 Space Scout As a child, Armstrong was a Boy Scout. On his way to the Moon, he sent a message to the Scouts back on Earth.

3 Hated the limelight Armstrong stayed out of the public eye after his return from the Moon, refusing to sign autographs and turning down many advertising offers.

4 Awards and honours Armstrong is one of the most honoured men in history and received several awards in his lifetime, including the Presidential Medal of Freedom – which is the highest civilian accolade in the United States.

5 Frequent flyer During his time as a test pilot, Armstrong logged over 1,000 hours of flights, and throughout his career flew over 200 different types of aircraft.

A life's work

A look at the key events in this astronaut's life that took him all the way to the Moon

1930 Neil Alden Armstrong is born in Ohio on 5 August to Stephen Koenig Armstrong and Viola Louise Engel.

1949 Armstrong is called into service during the Korean War, and flies over 75 combat missions.

1955 He graduates with a degree in Aeronautical Engineering from Purdue University.

1955 Armstrong begins work as an experimental test pilot at Edwards Air Force Base.

1956 Janet Elizabeth Shearon and Neil Armstrong marry, and go on to have three children.

1962 After joining the astronaut programme he moves to Houston, TX, with his family.

1966 As the command pilot for the Gemini 8 mission, Armstrong participates in the first docking of two vehicles in space.

1969 On 20 July, Neil Armstrong becomes the first man to ever walk on the Moon.

2012 Neil Armstrong dies due to complications following heart surgery. His family request that people 'wink at the Moon' in his honour.

© NASA

THE STATS
ANKYLOSAURUS

HEIGHT 2.5m
LENGTH 10m
LIVED 75-65.5 MYA
WIDTH 1.8m
WEIGHT 4,000-7,000kg
FIRST FOSSIL FOUND 1906

DID YOU KNOW? *Interestingly the earliest specimens of ankylosaurs we have found did not possess a tail club*

Ankylosaurus

A club-wielding brute of a creature, this tough dino had the power to break bones

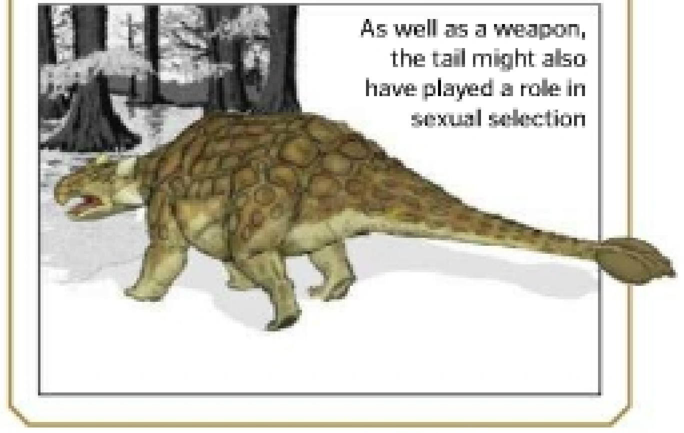
Ankylosaurus was one of the largest ankylosaurs, a genus of armoured dinosaurs that lived throughout North America between 75 and 65.5 million years ago. Famous for both its brutal tail-mounted club and its immense bone plate armour, the Ankylosaurus was a defensive titan, capable of fending off rivals many times its size.

Ankylosaurus's focus on defence was born out of its herbivorous nature, with its entire body geared towards the consumption of foliage. From its low-slung body, rows of leaf-shaped cropping teeth, short front legs, wide feet and cavernous stomach, the Ankylosaurus was the consummate browser, devouring vegetation whole with little shredding or chewing. Indeed, studies have indicated that the skull and jaw of the Ankylosaurus were structurally tougher than many similar, contemporary dinosaurs.

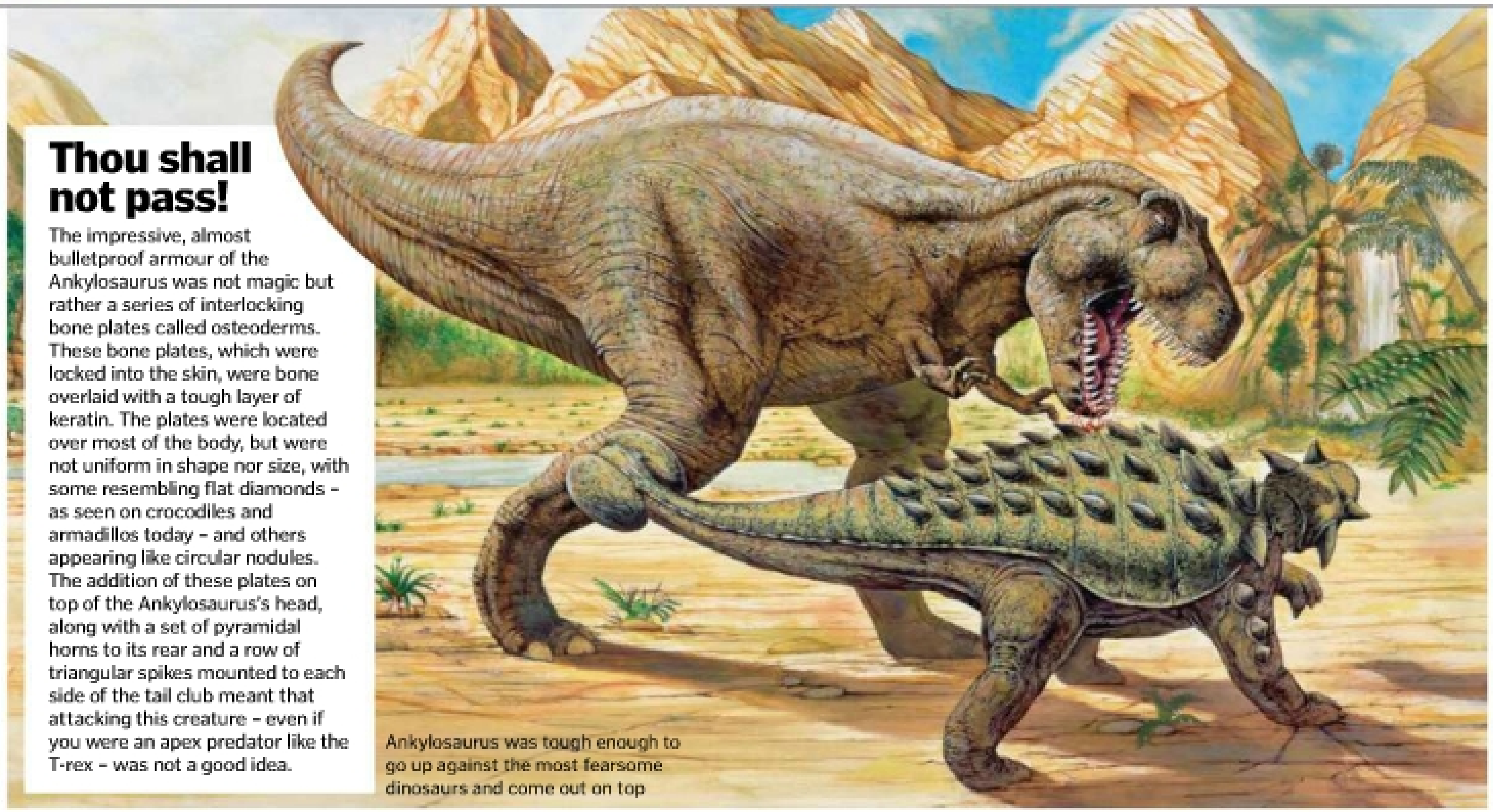
In fact, evidence suggests that Ankylosaurus – and ankylosaurs in general – were adept survivors. But despite their impressive armour, weaponry and sustainable diet, they could not cope with the Cretaceous-Tertiary extinction event that wiped out all terrestrial dinosaurs approximately 65.5 million years ago. Only a few fossils of this prehistoric herbivore have been excavated to date – most coming from the Hell Creek Formation in Montana, USA.

Club members only

The well-known tail club of the Ankylosaurus was one of the most lethal weapons sported by any dinosaur. The club was made from several large bone plates called osteoderms that were fused into the last few vertebrae of the animal's tail. Behind these vertebrae several others lined with thick, partially ossified tendons completed the club's handle, resulting in a structure that, when swung, was capable of dealing out a lot of damage. Indeed, a study in 2009 suggested that the tail clubs of fully grown ankylosaurs could easily crush and break bone with a force capable of caving in an assailant's skull. Whether or not the animal purposely aimed the club to cause damage remains unclear at this point.



As well as a weapon, the tail might also have played a role in sexual selection



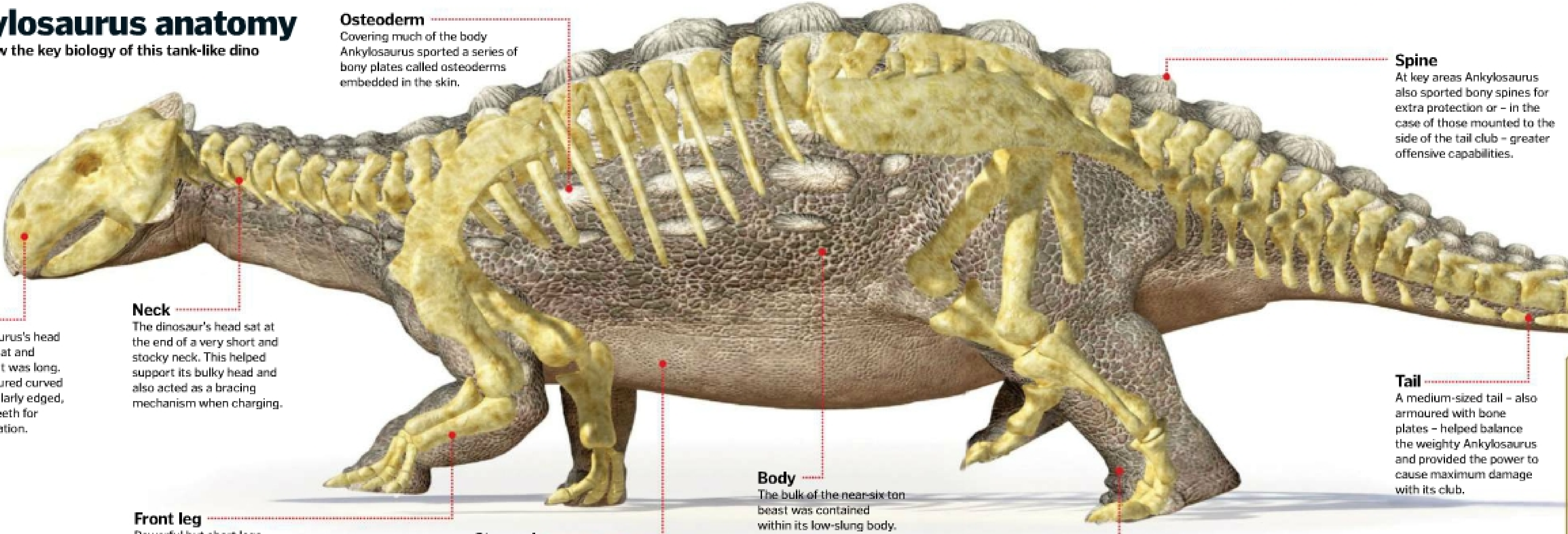
Thou shall not pass!

The impressive, almost bulletproof armour of the Ankylosaurus was not magic but rather a series of interlocking bone plates called osteoderms. These bone plates, which were locked into the skin, were bone overlaid with a tough layer of keratin. The plates were located over most of the body, but were not uniform in shape nor size, with some resembling flat diamonds – as seen on crocodiles and armadillos today – and others appearing like circular nodules. The addition of these plates on top of the Ankylosaurus's head, along with a set of pyramidal horns to its rear and a row of triangular spikes mounted to each side of the tail club meant that attacking this creature – even if you were an apex predator like the T-rex – was not a good idea.

Ankylosaurus was tough enough to go up against the most fearsome dinosaurs and come out on top

Ankylosaurus anatomy

Get to know the key biology of this tank-like dino



Osteoderm
Covering much of the body Ankylosaurus sported a series of bony plates called osteoderms embedded in the skin.

Head
The Ankylosaurus's head was square, flat and broader than it was long. The jaws featured curved rows of irregularly edged, leaf-shaped teeth for tearing vegetation.

Neck
The dinosaur's head sat at the end of a very short and stocky neck. This helped support its bulky head and also acted as a bracing mechanism when charging.

Front leg
Powerful but short legs supported the front half of the animal. The wide foot area of these forelegs granted good traction and stability.

Stomach
The only part of the dinosaur that was unarmoured, the underbelly hung low to the ground. Predators would try to tip ankylosaurs over to access this weak point.

Body
The bulk of the near-six ton beast was contained within its low-slung body. This was covered with armoured bone plating and topped with spines.

Rear leg
Equally powerful – if not more so – but longer than the Ankylosaurus's forelegs, the rear legs reached up to about 1.7m (5.6ft) at the hip.

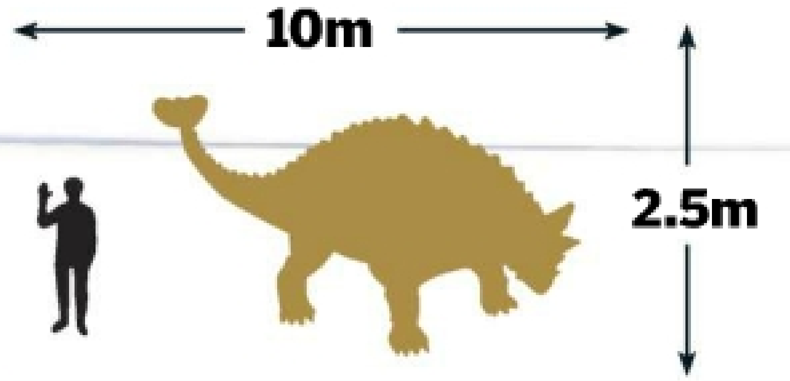
Tail
A medium-sized tail – also armoured with bone plates – helped balance the weighty Ankylosaurus and provided the power to cause maximum damage with its club.

Spine
At key areas Ankylosaurus also sported bony spines for extra protection or – in the case of those mounted to the side of the tail club – greater offensive capabilities.

Club
The characteristic tail club of Ankylosaurus was made from numerous osteoderms, each fused to the last few vertebrae of the tail.

Ankylosaurus vs human

How would this dino have sized up to a person?



© Alamy; Getty

"Paper documents were vulnerable to moisture, but placed on film they became all but impervious to it"

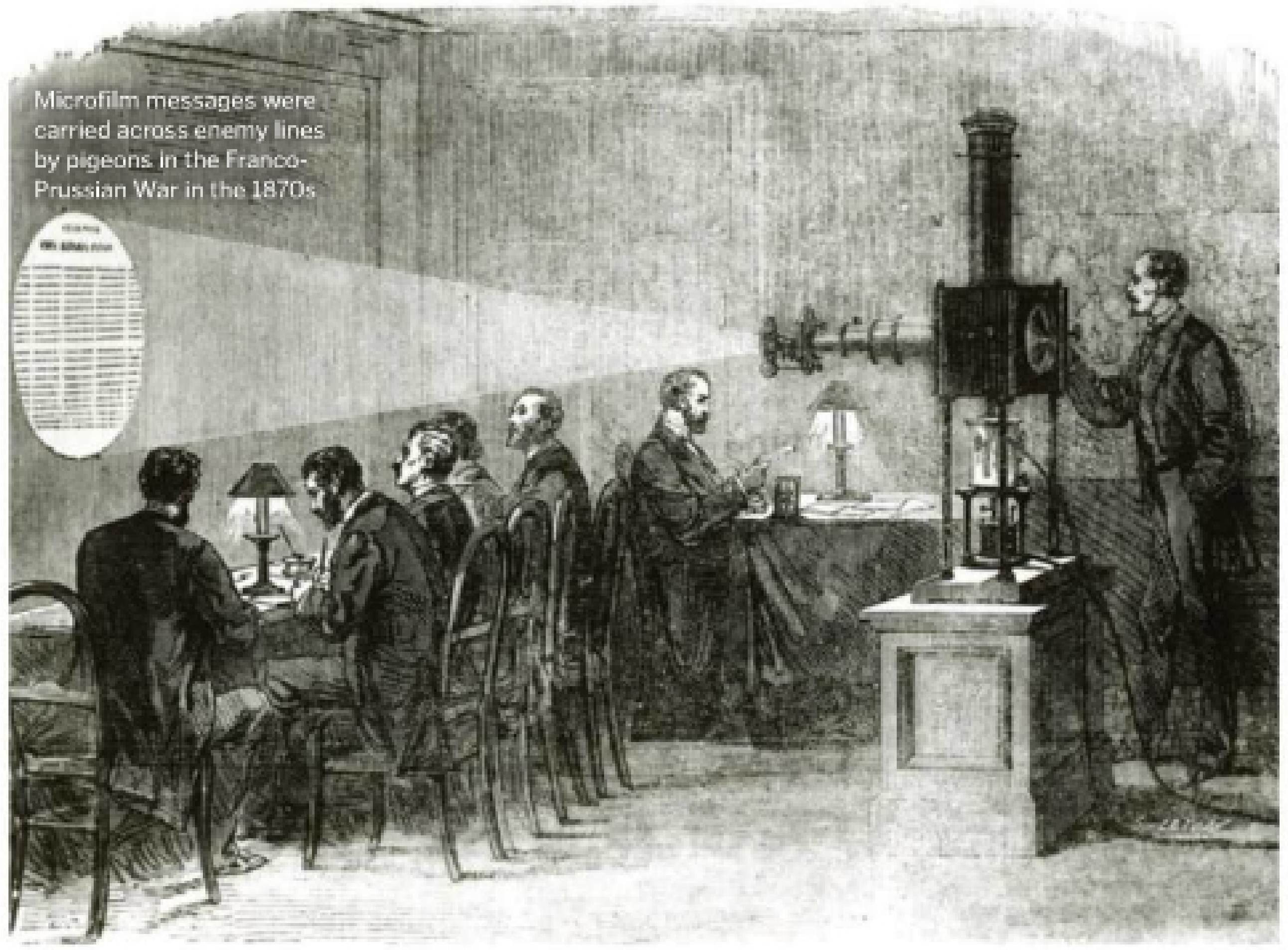
How did microfilm work?

The small-scale media storage that served as the perfect medium for covert messages

Microfilm was a physical storage media – typically 16-millimetre (0.6-inch) or 35-millimetre (1.4-inch) film – upon which images were reduced in size to a fraction of their former selves. This allowed documents, photographs and video footage to be shrunk, copied and stored for both secrecy and greater longevity. For example, historical paper documents were very vulnerable to moisture, but when imaged and placed on film they became all but impervious to it.

Often batches of documents were placed on one large sheet of microfilm with a readable code on top referred to as a microfiche – the code enabled the documents to be identified immediately. Viewing the stored image was achieved with a slide/film-based projection system (as pictured) that was similar to the overhead projectors we use today.

While microfilm is still used in select applications, the invention of the computer and virtual media has largely left it obsolete, with documents, images and films now copied and backed up on discs or cloud storage.



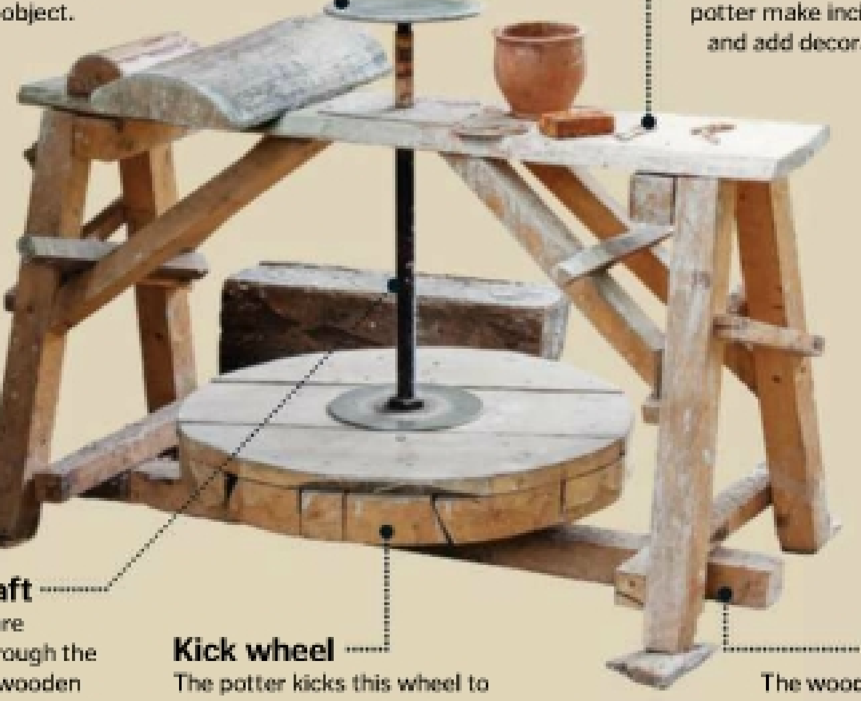
Microfilm messages were carried across enemy lines by pigeons in the Franco-Prussian War in the 1870s

How pottery was made

The potter's wheel turned the way we produce ceramics on its head

The potter's wheel enabled us to easily create round ceramic wares such as pots and gourds. The machine worked by supplying the potter with a rotating circular platform upon which, via hand moulding, clay could be shaped as desired. The rotation was provided by a large kick wheel, which once set in motion – the potter literally kicked it, hence the name – supplied energy to a smaller modelling wheel, which sat above on a metal shaft. As the kick wheel was much bigger than the modelling wheel, it acted as a flywheel, storing rotational energy that could be used to power the modelling plate, which due to its smaller circumference, span at a greater speed.

Thanks to its ease of use, the potter's wheel remained the method of choice for making pottery for many millennia, eventually evolving to be driven by a motor.



Modelling wheel
The potter shapes the clay material on this plate, which rotates at high speed while they model the object.

Tools
While pots are moulded with the hands, a number of small tools help the potter make incisions and add decoration.

Wheel shaft
Both wheels are connected through the centre of the wooden frame by a metal shaft.

Kick wheel
The potter kicks this wheel to start it rotating. It acts as a flywheel, storing energy and forcing the connected modelling plate to spin at high speed.

Frame
The wooden frame provides support for both the wheels and a surface for the potter to work on.

STRANGE BUT TRUE
CASTLE IN THE SKY

What is Himeji Castle believed to resemble?

A A bird **B** A plane **C** Superman

Answer:
Owing to its distinctive white plaster walls and the fact that the shape of the complex is said to resemble a bird taking flight, Himeji Castle is also often known by the names Shirasagi-jo (White Heron Castle) or Hakuro-jo (White Egret Castle).

DID YOU KNOW? During wartime, Japanese builders resorted to smashing up gravestones for construction materials

Inside a Japanese castle

We find out how Himeji Castle – a 17th-century fortification – has stood firm despite several centuries of conflict and natural disasters

Built on a hill 45 metres (150 feet) above sea level in southern-central Japan, Himeji Castle has survived innumerable feudal battles, sieges, earthquakes and even a WWII bombing. While today it's famed as Japan's largest castle, construction of the original site began in 1333 with the building of a small fort. The fort wasn't turned into a castle stronghold until nearly 250 years later, towards the end of the civil war era. The addition of three moats and dozens of extra buildings – including three large towers and a huge, six-storey main keep, or tenshu – saw the striking white complex become one of the greatest Japanese castles ever built.

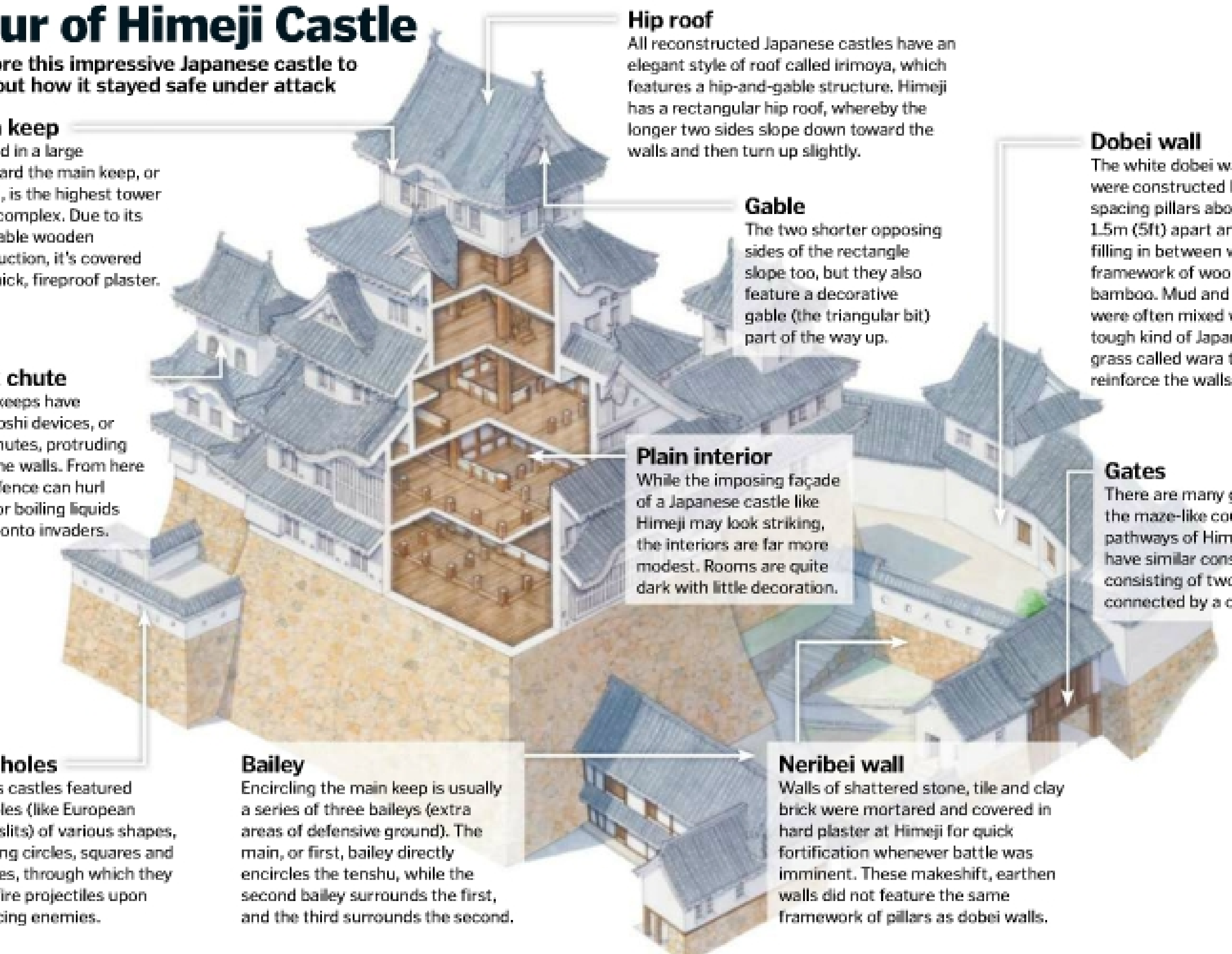
As is typical of traditional Japanese architecture, Himeji Castle is an elevated wooden structure featuring ornate tiling and embellishment. As well as gates, walls and other protective fixtures, Himeji and many other castles were equipped with a number of defensive devices to stall advancing foes.

Before they could even think about breaching the defences, the enemy would first have to navigate a frustrating maze of steep, snaking paths laid out around the castle walls. The physically demanding paths that seemed to lead directly to the main keep – but which often led instead to a dead-end – would disorientate and tire invaders. And even if they made it beyond the perimeter, the home team would then deploy an ingenious bevy of traps designed to outwit and injure the incoming aggressors, including conduits down which they would pour boiling oil or water.

Japan's best-preserved 17th-century castle, Himeji became a UNESCO World Heritage Site in 1993, which is quite remarkable considering what the region has endured, from earthquakes to attacks by US B-29 bombers. Of course, since the demolishment of the original 1333 fort, the castle has been rebuilt and remodelled by various rulers and architects, but what's interesting is that neither nature nor conflict has ever managed to get the better of Himeji.

Tour of Himeji Castle

Explore this impressive Japanese castle to find out how it stayed safe under attack



Main keep
Located in a large courtyard the main keep, or tenshu, is the highest tower in the complex. Due to its vulnerable wooden construction, it's covered with thick, fireproof plaster.

Hip roof
All reconstructed Japanese castles have an elegant style of roof called irimoya, which features a hip-and-gable structure. Himeji has a rectangular hip roof, whereby the longer two sides slope down toward the walls and then turn up slightly.

Gable
The two shorter opposing sides of the rectangle slope too, but they also feature a decorative gable (the triangular bit) part of the way up.

Dobei wall
The white dobei walls were constructed by spacing pillars about 1.5m (5ft) apart and filling in between with a framework of wood and bamboo. Mud and clay were often mixed with a tough kind of Japanese grass called wara to reinforce the walls.

Rock chute
Many keeps have ishi-otoshi devices, or rock chutes, protruding from the walls. From here the defence can hurl rocks or boiling liquids like oil onto invaders.

Plain interior
While the imposing façade of a Japanese castle like Himeji may look striking, the interiors are far more modest. Rooms are quite dark with little decoration.

Gates
There are many gates among the maze-like courtyards and pathways of Himeji, but all have similar construction, consisting of two columns connected by a crossbeam.

Loopholes
Japan's castles featured loopholes (like European arrow slits) of various shapes, including circles, squares and triangles, through which they could fire projectiles upon advancing enemies.

Bailey
Encircling the main keep is usually a series of three baileys (extra areas of defensive ground). The main, or first, bailey directly encircles the tenshu, while the second bailey surrounds the first, and the third surrounds the second.

Neribei wall
Walls of shattered stone, tile and clay brick were mortared and covered in hard plaster at Himeji for quick fortification whenever battle was imminent. These makeshift, earthen walls did not feature the same framework of pillars as dobei walls.

© Thinkstock

> *"The Mona Lisa is kept in a clear container with controlled humidity, temperature and light levels"*

5 TOP FACTS
THE MONA LISA

What a steal
1 The *Mona Lisa* was actually stolen from the Louvre museum in Paris on 21 August 1911. However the work of art was later recovered in Italy and returned in 1913.

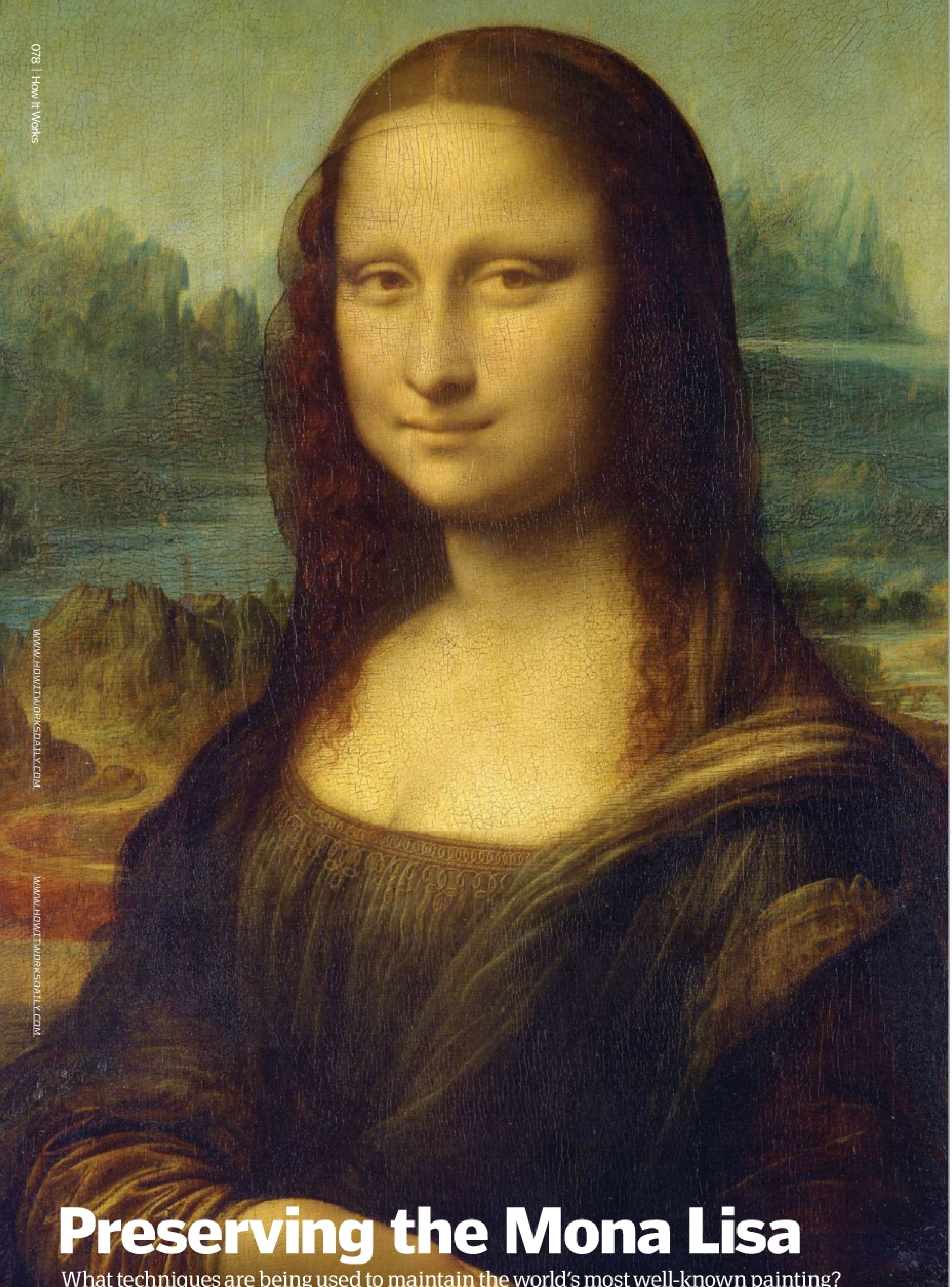
Bulletproof
2 Today the *Mona Lisa* is displayed behind a bulletproof glass enclosure to prevent damage by vandals, which has been attempted a number of times over the years.

Saving face
3 As the *Mona Lisa* is over 500 years old it has gone through a number of renovation and conservation programmes – the latest seeing it lit by a 20-watt LED lamp.

Popular lady
4 In its current position in the Louvre, the *Mona Lisa* is viewed by over 6 million people per year. As a result it's one of the most viewed paintings on the planet.

Worth millions
5 In 1962 it was assessed at £64.5 million ($100 million). In 2013 it's worth over £489.5 million ($760 million), easily making it the world's most expensive painting.

DID YOU KNOW? *Infrared images of the painting have revealed Da Vinci's original sketch marks beneath the paint/varnish*



Preserving the Mona Lisa

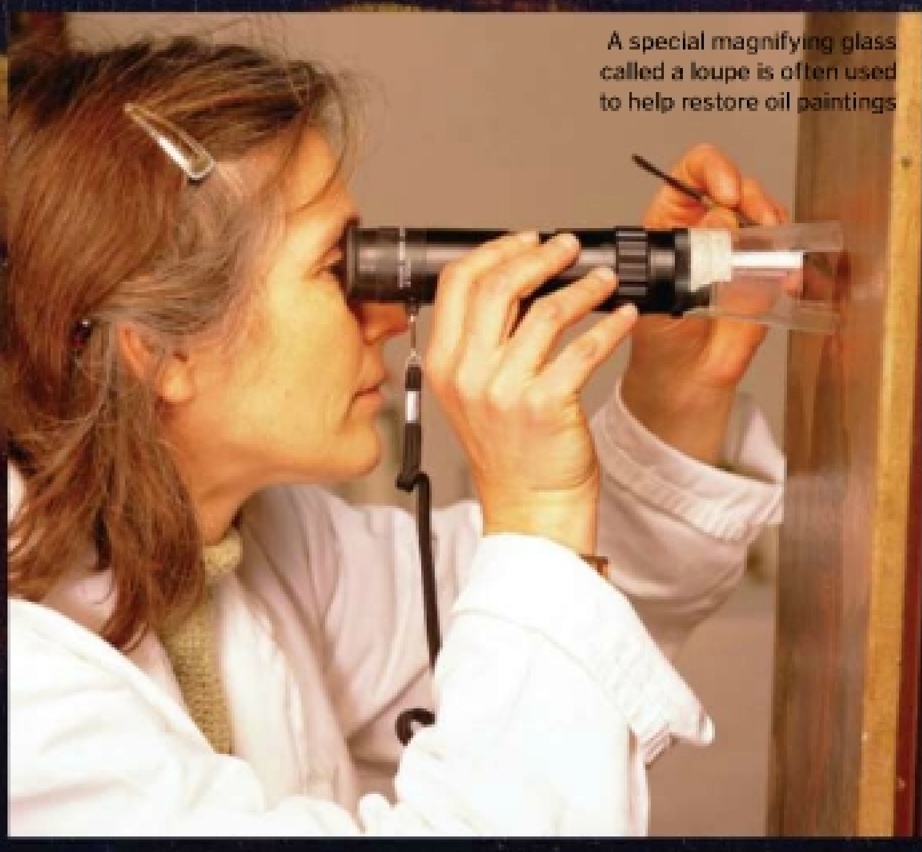
What techniques are being used to maintain the world's most well-known painting?

The *Mona Lisa* is an oil painting on a poplar wood panel by Leonardo da Vinci. Believed to be a half-length portrait of Lisa del Giocondo (maiden name Gherardini) – the little-known wife of a Florentine cloth and silk merchant – it's considered the most famous painting on Earth, with millions viewing it every year at the Louvre museum in Paris, France.

As the *Mona Lisa* is over 500 years old, an intensive conservation effort is ongoing to preserve it. This conservation is split into two main areas: frame rectification and painting restoration. The frame is the most altered part of the *Mona Lisa* to date, with the original poplar frame warping to the extent that by the start of the 20th century, a crack had developed. This crack was secured by installing two butterfly-shaped walnut braces into the poplar panel and then later a flexible oak frame and pair of cross braces. Today this physical manipulation is partnered with a closely monitored environment, with the *Mona Lisa* kept in a clear container with controlled humidity, temperature and light levels.

Restoration of the painting itself has gone on for centuries, having first received a wash and new coat of varnish back in 1809. This involved the painting being cleaned with spirits, having specific colours touched up and then being revarnished. Following its theft and return in the early-20th century, the painting was worked on once more, with a number of scratches filled in with watercolour.

Finally, following an attack on the painting by vandals in 1956 which caused damage to the left elbow of the figure, this was also repainted with watercolours. Today, work continues on the *Mona Lisa* to restore much of the colour to the enigmatic portrait, with the wash carried out in 1809 now believed to have removed the top layer of paint. ✽



A special magnifying glass called a loupe is often used to help restore oil paintings

©SPL

BRAIN DUMP

Because enquiring minds need to know...

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Why we yawn is not yet completely understood, but it could have evolved to stretch facial muscles or as a means of communication

Why do we yawn and is it contagious?

Francesca

■ Nobody is 100 per cent certain why humans yawn, but it definitely is contagious: in one experiment half of the people yawned while watching a video of others yawning. A common theory is that the influx of oxygen from a good yawn revives us by getting rid of excess carbon dioxide in our blood – although some research is now refuting this idea. Instead, we may yawn simply to stretch our tongue and throat muscles, as well as to communicate boredom or tiredness to our peers. One recent study even suggested that yawning may help to regulate brain temperature by exposing the roof of the mouth to cooler air – a bit like a heat sink. **AC**

Meet the experts...

Luis Villazon

Luis has a degree in zoology and another in real-time computing. He's been writing about science and technology since before the web. His science-fiction novel, *A Jar Of Wasps*, is published by Anarchy Books.

Giles Sparrow

Giles studied Astronomy at UCL and Science Communication at Imperial College, before embarking on a career in space writing. His latest book, published by Quercus, is *The Universe: In 100 Key Discoveries*.

Rik Sargent

Rik is an outreach officer at the Institute of Physics in London, where he works on a variety of projects aimed at bringing physics to the public. His favourite part of the job is what he calls 'physics busking'.

Alexandra Cheung

With degrees from the University of Nottingham and Imperial College, Alex has worked at many a prestigious institution including CERN, London's Science Museum and the Institute of Physics.

Michael Simpson

Michael has a doctorate in moss as well as teaching awards from the University of Alberta. While not working as a botanist or environmental consultant, he writes for magazines and online.

Who invented the tea ceremony?

Lizzie Stokes

■ No one person is credited for inventing the Japanese tea ceremony but several historical groups are thought to have contributed to its development. The ceremony has links with Zen Buddhism, which was founded in Japan near the end of the 12th century. Tea became part of Buddhist rituals and is still associated with tranquillity and harmony today. Tea also became popular with samurai warriors and nobles, who made it the centre of a party game. They were considered celebrities in their day so their appreciation of tea might have encouraged other people to adopt the drink, along with the rituals associated with it. **MS**

Can we tame tigers?

Vivienne Jones

■ Not in the way you might tame a dog or break in a horse. Dogs and horses have been domesticated for millennia and selective breeding has gradually favoured the genes that make them more friendly. Tigers – even raised from a cub – retain all their predatory instincts. In Thailand, 'tame' tigers live in a monastery, side by side with the monks and tourists, but it's a precarious balance. Roy Horn of the entertainment double act Siegfried & Roy was critically injured in 2003 when the tiger he had performed with for six years bit him. **LV**

You will spread the life's work of at least 20 bees on a single slice of toast!

How much honey does a bee make in its lifetime?

Ben

■ Less than a gram. Most worker bees only live for around six weeks in the summer and they can only go and forage for nectar on days when the air temperature is above ten degrees Celsius (50 degrees Fahrenheit). A group of about 12 bees in their lifetime will produce a teaspoon of honey between them. Bees use their honey as an energy source for the hive. Depending on the weather, a hive might use over 20 kilograms (44 pounds) of honey over a single winter. **LV**

How do you know if berries are poisonous?

Ryan Mann

■ There aren't really any distinctive features we can use to reliably distinguish berries that are poisonous so your best bet is to build up a thorough knowledge of plants or a good guide. Some people advise against eating berries that are white or yellow, or that grow on vines, because they say these are typically bad for you. Most purple, blue or black berries, however, are said to be okay. Yet grapes grow on vines while deadly nightshade berries can appear purplish-black and are highly toxic. The best rule is not to eat the fruit of any wild plant unless you know for sure that it's safe. **MS**

5-SECOND FACTS

The brain can hold thousands of gigabytes of data

If each of our brain's neurons is equivalent to a 'bit' of computer memory, then the overall storage capacity may be around ten gigabytes. But in reality our brains are wired up completely different from computers, with many trillions of connections between individual neurons. This means that the brain's capacity could be many terabytes.

Even deserts get snow

It can indeed snow in the desert. Deserts are not defined by how warm they are, but by how little rainfall they receive. Indeed, Earth's largest desert is Antarctica – the coldest, driest and windiest continent on the planet – where heavy snow is quite common.

Which is the planet's most noisy creature? Find out on page 82

Want answers?

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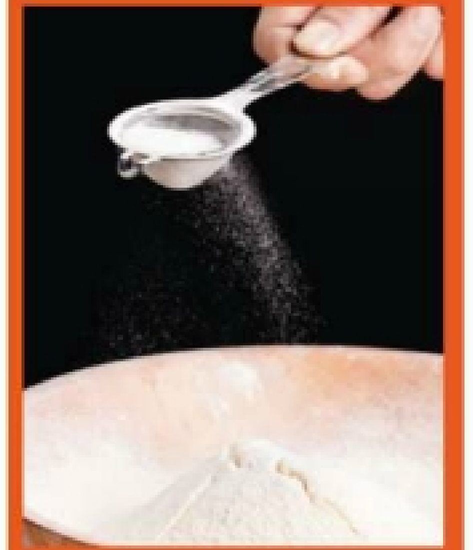
howitworks@imagine-publishing.co.uk

5-SECOND FACTS

Flour can be explosive

Like all starches, flour is flammable, but it's only liable to explode when it's suspended in the air, which is why mills and bakeries have to be particularly careful. Surrounded by oxygen, each tiny particle of flour burns almost instantly, igniting the particles around it and allowing the flame to propagate very rapidly to generate an explosion.



Human heads may have once been used to play football

The oldest leather football in existence was unearthed at Stirling Castle in Scotland and dates back to the early-1500s. Centuries before that, however, people were kicking balls that are believed to have been made of animal bladders, skulls or even human heads! More familiar vulcanised rubber footballs were only introduced in the 19th century.

They might be small, but pistol shrimps certainly know how to make themselves heard…

Which is the loudest animal?

Alex Wells

It's the tiger pistol shrimp. The pistol shrimp has one supersized claw that can be cocked open. When 'fired' the claw snaps shut with such speed that a jet of water is fired out at 97 kilometres (60 miles) per hour. The low-pressure wake creates a cavitation bubble of steam that explodes outwards and then almost instantly collapses again. The collapsing bubble is what generates the sound, which can be up to 218 decibels. The sound is used partly for communication, but its main purpose is as a weapon. The shockwave is loud enough to stun fish and even shatter glass. Because it is very high frequency, the shrimp's click doesn't reach very far. The loudest sound used purely for communication, meanwhile, is made by the blue whale, which sends 188-decibel whistles that can be heard 800 kilometres (500 miles) away! **LV**

What percentage of stars go supernova?

Traci Watson

We can't be specific, but it's without a doubt much less than one per cent. Stars that end their lives in supernova explosions must have at least eight times the mass of the Sun, so that they blow up into a supergiant star and then violently collapse, instead of gently shedding their outer layers and fizzling out like smaller stars do. The reason we can't be sure of a percentage is partly because we don't fully understand how such massive stars form and develop through their lives (sometimes in ways that stop them becoming supernovas), and partly because we've only a vague idea of the quantity of much fainter and lower-mass stars that massively outnumber them in the universe. **GS**

Why are raccoons invading cities more and more?

James Cooper

It's the same reason humans move to the cities: life there is easier. Raccoons are omnivores and scavengers and they find it much easier to grab discarded food in a dustbin than to catch it in the wild. There are also fewer predators in the city. Raccoons are mostly nocturnal and the only animals that would pose a serious threat – dogs – are generally tucked up indoors or chained in the garden at night. Raccoons are very intelligent, can wriggle into tight spaces and have nimble front paws for undoing latches and opening containers. Toronto now has 50 times more raccoons than the surrounding countryside. **LV**

What mechanisms support aeroplane wings on the ground?

R Hickman

Wings can be held up by wires or braces on the fuselage and they are also supported by their internal structure. Components that are concealed under the aluminium or composite wing casing include ribs and stringers. The former run parallel to the fuselage and are attached at regular intervals along the wing. The latter run along the length of the wing and connect the ribs. Support is also provided by the spar, which runs parallel to the stringers. An aircraft's fuel is sometimes stored between the ribs and this too can lend more rigidity to the wings. **MS**

Does electricity ever weigh anything?

Samuel Mycroft

The term electricity includes several different phenomena, but none of these have any weight. To weigh something (that is, to experience the Earth's gravitational pull), an object needs mass. An electric current is created when charged particles move – eg electrons in a copper wire. While these electrons have a tiny amount of mass, they exist in the wire whether or not a current is applied, so the wire's mass doesn't change. The electric force (which causes particles with the same charge to repel each other, for instance) has no weight as forces don't have mass. The only electric phenomenon which might arguably weigh something is the buildup of a static charge, when an object gains excess electrons. In this case, the extra electrons would add to the object's mass, but the weight difference would be nominal. **AC**

How much gold is in the world?

Sarah Blain

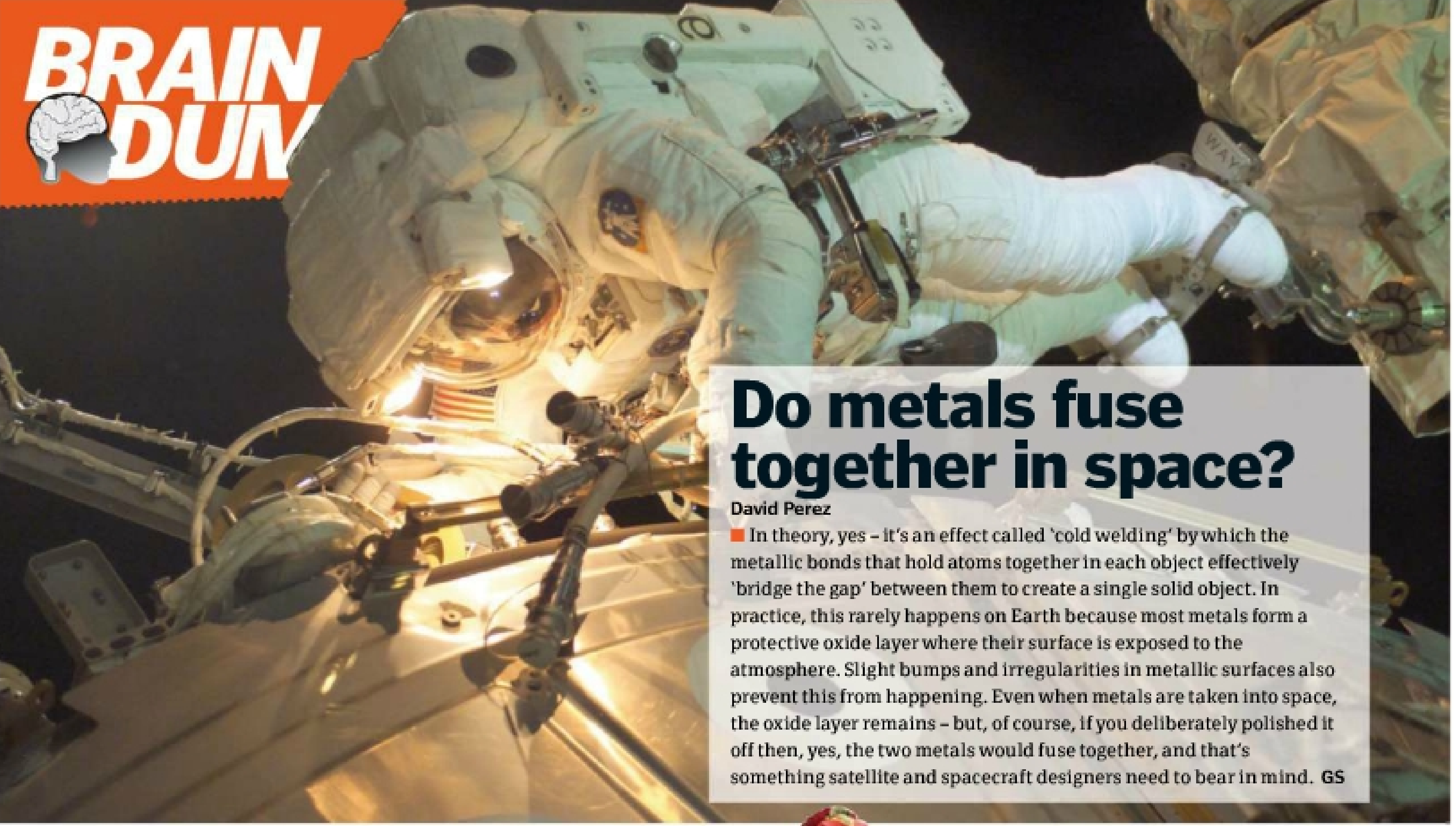
According to the annual world gold survey by Thomson Reuters, the total amount of gold mined in the history of the world is 171,300 tons – enough to fill a cube with 20.7-metre (68-foot) sides. But opinions differ, mainly because experts can't agree on how much was mined by ancient civilisations, and how much is hidden in the world's bank vaults. So it might be a little less, or a lot more; the Gold Standard Institute estimates there may be as much as 2.5 million tons hidden away out there! On top of that, the US Geological Survey estimates there is about 52,000 tons to still be profitably mined, with huge quantities locked deep within the Earth's interior. **GS**

How fast is it possible to go?

Jason Garside

The absolute speed limit of the universe is the speed at which light travels in the vacuum of space – 299,792 kilometres (186,282 miles) per second, or 'c'. Nothing can go faster than this as doing so would enable it to violate the basic laws of cause and effect. Einstein's special theory of relativity explains the effect this has on the laws of physics – eg if you had a spaceship that was powerful enough to travel close to c, you'd find accelerating those last few per cent got harder and harder, as the craft got heavier and heavier. No object with mass can ever reach c itself – light can only travel so fast as it is massless. That said, light travels more slowly when it passes through materials such as water and glass, hence why it bends, or refracts. **GS**

Where did Chinese dragons originate? Find out on page 84



Do metals fuse together in space?

David Perez

■ In theory, yes – it's an effect called 'cold welding' by which the metallic bonds that hold atoms together in each object effectively 'bridge the gap' between them to create a single solid object. In practice, this rarely happens on Earth because most metals form a protective oxide layer where their surface is exposed to the atmosphere. Slight bumps and irregularities in metallic surfaces also prevent this from happening. Even when metals are taken into space, the oxide layer remains – but, of course, if you deliberately polished it off then, yes, the two metals would fuse together, and that's something satellite and spacecraft designers need to bear in mind. **GS**

5-SECOND FACTS

Saturn is not the only planet with rings

While Saturn's rings are something of an iconic feature, the three other gas giants – Jupiter, Uranus and Neptune – also have their own set. The rings consist of tiny particles of cosmic dust, resulting from collisions and leftover matter that didn't coalesce, held in place by the large bodies' immense gravity.

A polar bear would beat a brown bear

The common brown bear has longer claws than a polar bear, but it's smaller on average. Polar bears also have up to ten centimetres (four inches) of blubber underneath their skin which acts as good armour. Polar bears and brown bears very rarely fight in the wild though, and actually sometimes interbreed.

Why do Chinese dragons resemble snakes?

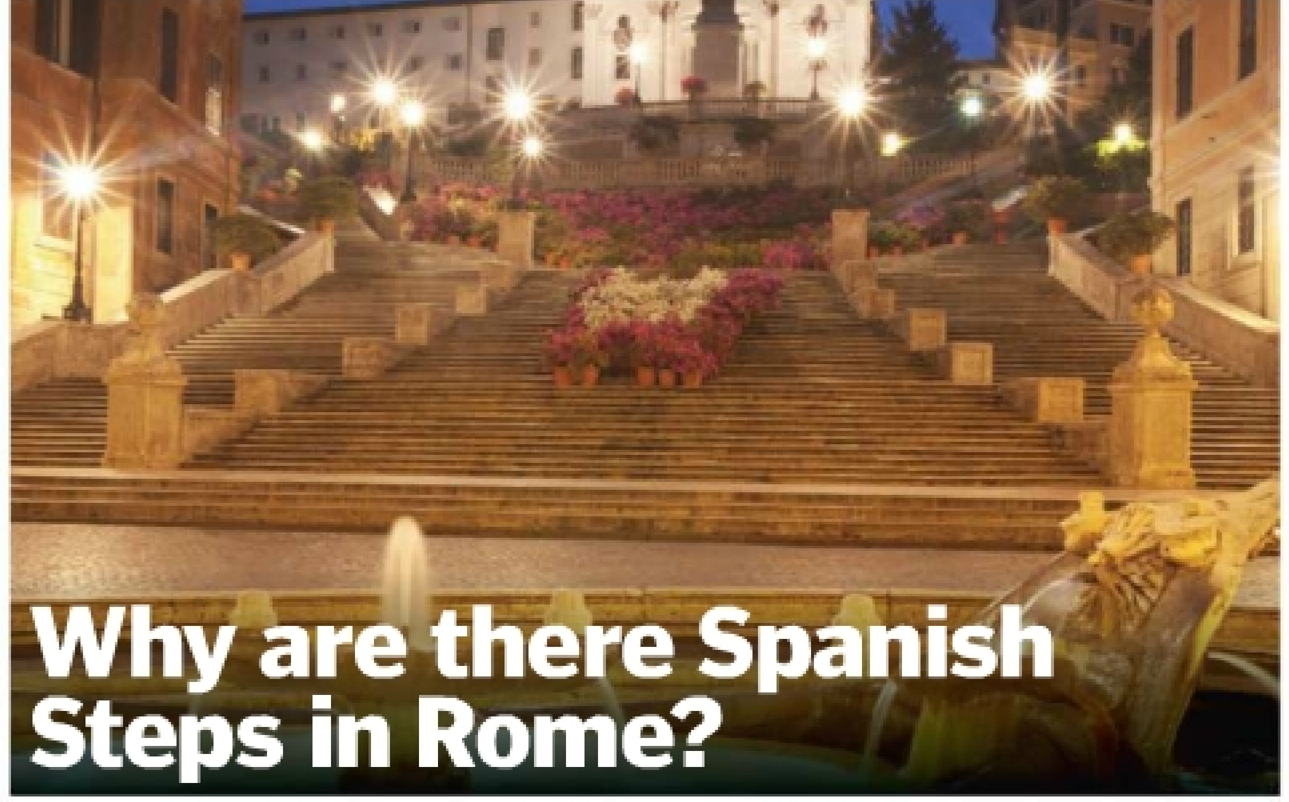
Jessica

■ Mythical snake-like dragons date back to artefacts discovered in north-east China as early as 5000 BCE, but it is not known why they resemble snakes. The earliest depictions of dragons were called pig dragons – small jade sculptures featuring a pig's head with a coiled body. Early versions looked more like a foetus, with the longer serpentine body becoming popular later. In Chinese culture, dragons are synonymous with water and are said to be the masters of rainfall, waterfalls, rivers and seas. This could partly explain the serpent-like form, as a swimming mechanism similar to an eel, or perhaps the wavy snake-like shape, was a reason dragons became associated with water. Traditionally, it's not only snakes that dragon depicters have borrowed from – there are many other anatomical resemblances found in Chinese dragons, including stag horns, carp scales, tiger feet and eagle claws. **RS**

Why is beeswax perfect for candles?

Melissa Davidson

■ Beeswax is solid at room temperature but melts easily and burns slowly, producing very little smoke and emitting a sweet smell. These qualities make it ideal for candle-making although whether or not it is the best material remains subjective. Early candles were made from tallow, processed from animal fat. Tallow candles smelled unpleasant and burned quickly, so beeswax offered big benefits over these. Nowadays, there are many alternatives to beeswax. Most candles are made from paraffin wax, which is odourless, clean and cheap, but other materials such as soybean wax are also popular. **AC**



Why are there Spanish Steps in Rome?

Nathan Moore

■ The Spanish Steps, or Scalinata della Trinità dei Monti, link Piazza di Spagna (Spanish Square) with the French church Trinità dei Monti. The Spanish connection comes from the presence in the piazza of the Spanish Embassy to the Holy See (Vatican City). Construction of the stairway began in 1723 and took several years to complete. It was designed by an Italian architect, Francesco de Sanctis, and funded by money bequeathed posthumously by a French diplomat, Étienne Gueffier. The pathway formed by the steps between the church above and the square below was a symbol of improved co-operation between France and Spain. They were originally named after Trinità dei Monti but that was later superseded. The Spanish Steps are now one of the most popular – and crowded – tourist destinations in Rome. **MS**

Why does cooking bacon smell so good?

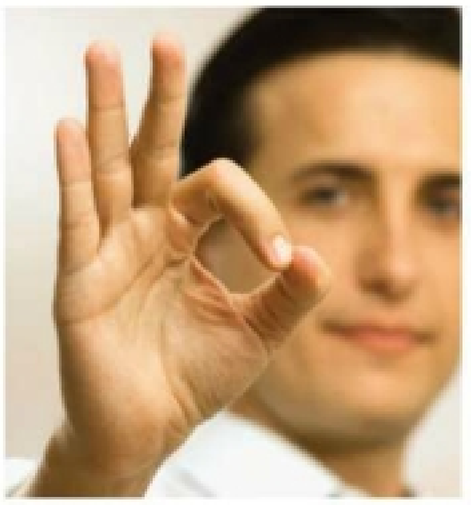
Lucy P

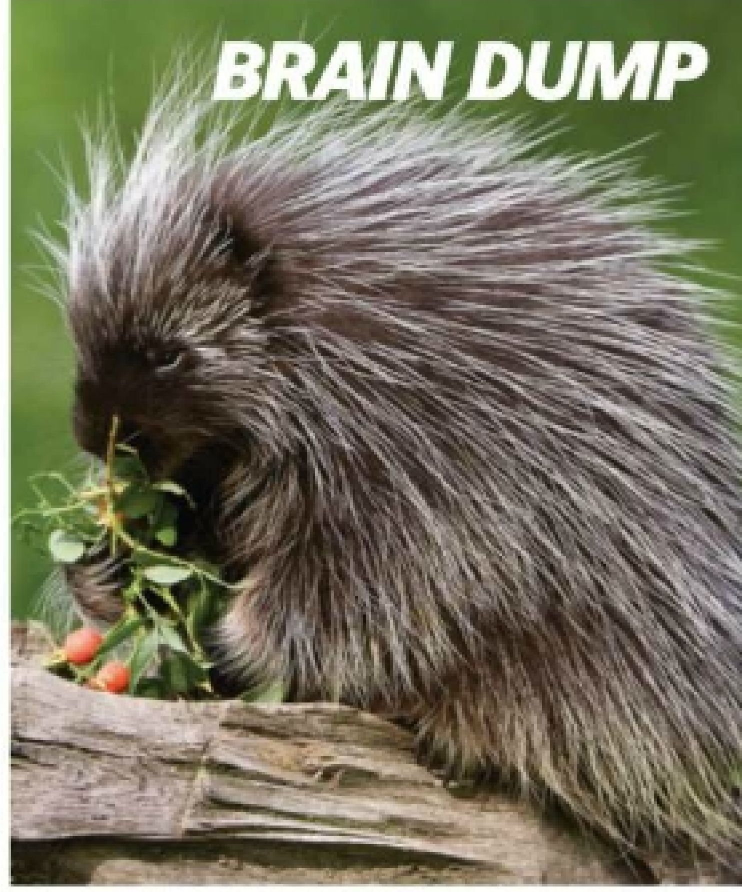
■ Bacon's mouth-watering smell comes from the meat's amino acids and sugars reacting to heat. Known as the Maillard reaction, the process releases hundreds of compounds associated with desirable aromas and flavours, resulting in a complex assault on our senses. Our brains have evolved to recognise these smells as good, presumably due to the survival advantage that heating food had for our ancestors. The Maillard reaction also happens when you toast bread or roast coffee beans, although different compounds are given off. Some of the compounds have similar characteristics and are often described by food scientists as nutty, smoky and caramel-like. **RS**

What does 'OK' actually stand for?

Emma P

■ OK stands for 'oll korrect', or 'ole kurreck', and comes from an abbreviation trend which was popular in Boston, MA, back in the 1830s. Other popular abbreviations at the time were NG, ('no go'), GT ('gone to Texas') and SP ('small potatoes'). Many of the abbreviations were deliberately spelt incorrectly for humorous effect; for example, a predecessor of OK was supposedly OW ('oll wright'). OK gained widespread use when supporters of the American Democratic political party stated that it stood for the nickname of presidential candidate Martin Van Buren, aka Old Kinderhook. 'Vote for OK' became a snappy campaign slogan that popularised the use of OK across the USA. **RS**





Can porcupines float on water?

Sam Gunn

■ Porcupines are buoyant, thanks in part to the hollow structure of their quills. These sharp spines are solid at the base and tip but mostly hollow in the middle, with a light spongy material (the quill medulla) sealed off inside. This helps porcupines float, but although North American, crested and brush-tailed porcupines are keen swimmers, not all porcupine species are fond of water. Porcupine quills are even sometimes used by fishermen as floats. The main function of quills, though, is for defence. North American porcupines have up to 30,000 quills each measuring around ten centimetres (four inches) long; if a predator gets too close the barbed tips snag into their skin. **AC**

Fact fix on the go

■ The latest issue of Imagine's new, digital-only science magazine, **Brain Dump**, is now available from Apple's Newsstand. Overflowing with the snappiest, most authoritative and just downright awesome explanations to Earth's most important scientific questions, the current issue is the most informative and entertaining yet, answering a bucketload of amazing reader-submitted queries. Questions like, can we clone extinct animals? Why do we sleepwalk? How do Venus flytraps work? And why is electricity blue? All of these are answered along with many more. So to learn more about **Brain Dump** and the amazing content on offer in this and every issue, head over to the Apple Newsstand, pay a visit to the magazine's Facebook page at www.facebook.com/BraindumpMag or, alternatively, take a look on its Twitter stream @BrainDumpMag now.

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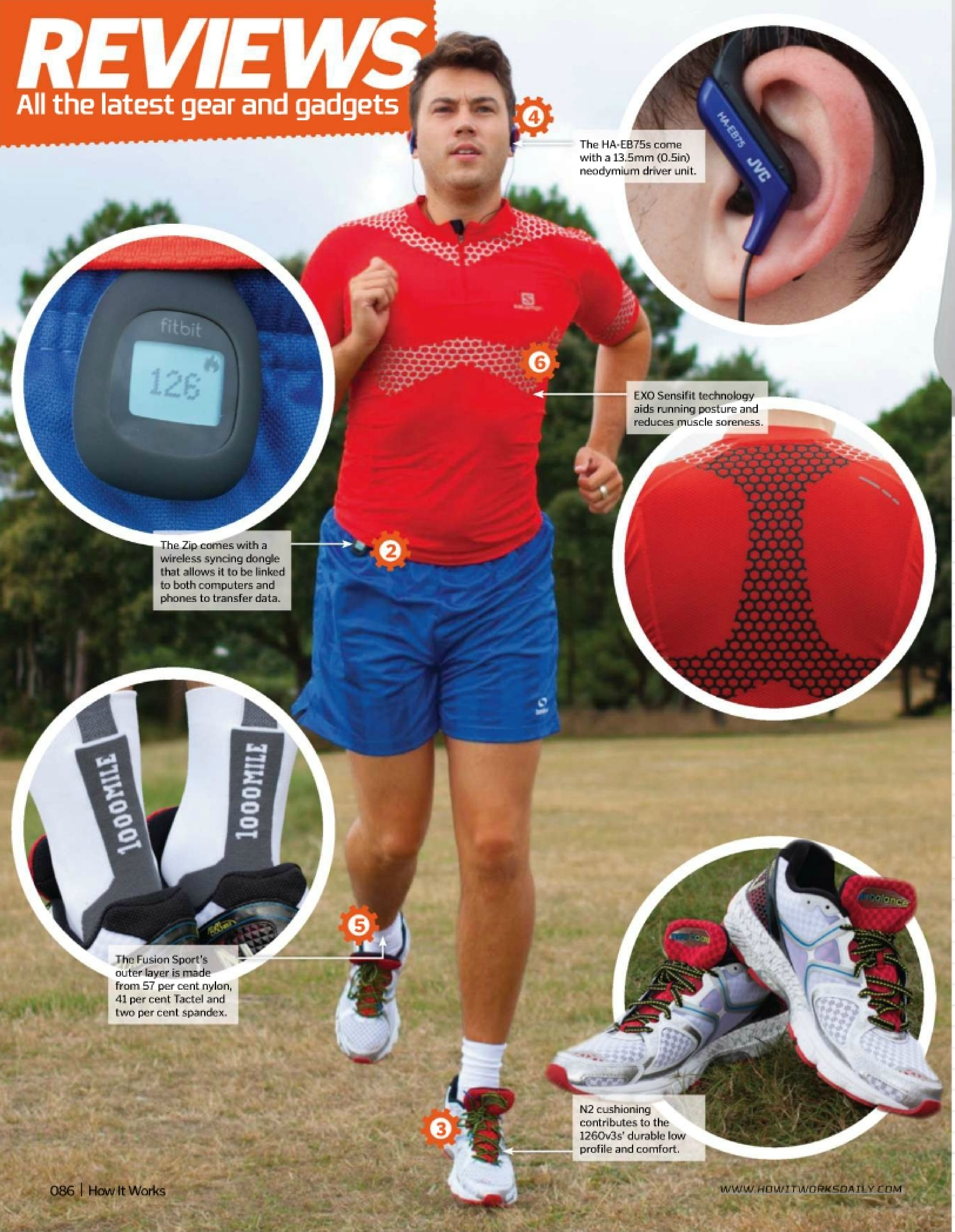


④ The HA-EB75s come with a 13.5mm (0.5in) neodymium driver unit.

⑥ EXO Sensifit technology aids running posture and reduces muscle soreness.

② The Zip comes with a wireless syncing dongle that allows it to be linked to both computers and phones to transfer data.

⑤ The Fusion Sport's outer layer is made from 57 per cent nylon, 41 per cent Tactel and two per cent spandex.

③ N2 cushioning contributes to the 1260v3s' durable low profile and comfort.

① Up to eight users can store their profile information in the Aria for multi-runner households.

The materials in the EXO S-Lab support the body but allow easy movement

Get running

Must-have kit to get off on the right foot

With the summer now drawing to a close, what better way to prepare yourself for the onslaught of the cold and overindulgent months than by getting in shape with a little running? While putting your body through the ringer is never easy, dedicated technology and clothes are making it more convenient and more comfortable than ever before, as we discover here.

Checklist
- ✓ Interactive scales
- ✓ Activity tracker
- ✓ Running shoes
- ✓ Headphones
- ✓ Sport socks
- ✓ Running T-shirt

1 Measuring BMI

Fitbit Aria Wi-Fi Smart Scale
£99.99/$129.95
www.fitbit.com

If you're serious about getting in shape be prepared for a long journey. Weight loss and muscle tone don't just happen over night. Luckily, the Fitbit Aria Wi-Fi Smart Scale makes this more bearable, measuring, storing and tracking up to eight users' body fat percentage, weight and body mass index (BMI). This data can be wirelessly streamed via Wi-Fi to a PC, where included software converts it into a variety of graphs and charts. All together this is an excellent motivational fitness tool.

Verdict: ●●●●●

4 Sweat proof

JVC HA-EB75 headphones
£12.99/$12.95
www.amazon.com

Running headphones need two things: a secure fit and water resistance. This is because there's nothing more annoying than having earphones constantly jiggling free and falling out when you're trying to run, or packing up the first time it rains or they get sweaty. The great-value-for-money JVC HA-EB75s deal with these criteria well thanks to special ear clips and moisture-resistant earbuds, while a neodymium driver unit delivers surprisingly decent audio to boot, with a good level of bass.

Verdict: ●●●○○

2 Activity tracking

Fitbit Zip
£49.99/$59.95
www.fitbit.com

There's a bounty of activity trackers on the market today, ranging from £20 right through to £200 or even more. The Fitbit Zip comes in right at the sweet spot for this category of devices, offering a small and stylish activity tracker for a penny shy of £50. Capable of recording a runner's steps, distance and calories spent, the Zip is versatile, while its ability to wirelessly sync with a computer or smartphone makes keeping track of progress more straightforward than ever.

Verdict: ●●●●○

5 Dual-layer socks

1,000 Mile Fusion sport socks
£11.99/$N/A
www.1000mile.co.uk

Often overlooked when it comes to running kit, the average sock is actually not well suited to the discipline and, as a result, they can often cause blisters and red-raw skin. The 1,000 Mile Fusion sport socks go a long way to rectify this predicament, with a two-layer construction, padded Achilles' tendon support structure and moisture-repellent Tactel inner material keeping your feet in prime condition during exercise. Of course, at £12 a pair, this luxury comes at a premium.

Verdict: ●●●●○

3 Lightweight foam

New Balance 1260v3 shoes
£124.99/$144.99
www.newbalance.com

When running, your feet are the most active part of your body so a good pair of running shoes is vital. A brand-new entrant to New Balance's catalogue of fitness-focused sport shoes, the 1260v3s are an excellent example, offering superb support and cushioning. In addition, the trainers' Acteva Lite foam is 24 per cent lighter than other foams and provides enhanced resistance to compression under impact, granting better spring and comfort over long distances.

Verdict: ●●●●○

6 Muscle support

Salomon EXO S-Lab Zip T-shirt
£80/$100
www.salomon.com

The EXO S-Lab Zip tee is not only very comfy to wear thanks to its flatlock seams, but also loaded with smart tech. Firstly the EXO has been designed to improve upper body posture, with areas of compression and support improving oxygen intake while running. Secondly, the inclusion of Salomon's Actilite II Stretch Mesh means that any sweat is repelled fairly quickly. Lastly, by using different materials, such as polyester and spandex, each area of the T-shirt is designed for optimum movement.

Verdict: ●●●●●

EXTRAS

Three top resources to keep you on track with your running...

BOOK

Running for Beginners

Price: £9.99/$N/A
Get it from: www.imagineshop.co.uk

Running for Beginners is a fantastic resource for anyone new to the sport. Written by dedicated fitness enthusiasts, this superb title is aimed at those looking to take up running for the first time, covering everything from training to gear and how to stay motivated.

APP

Zombies, Run!

Price: Google Play £2.79/$3; iTunes £2.49/$3.99
Get it from: Google Play/iTunes

A fitness app that differs from the norm, Zombies, Run! casts you as a survivor of a zombie apocalypse as a supplies gatherer. As you run around you're given missions to complete and, as you might expect, zombies are constantly on the prowl attempting to grab you – as you'll hear through your headphones. If you don't want to be dinner, you'd better speed up!

WEBSITE

LetsRun.com

Despite its rather Nineties-looking design, **www.letsrun.com** is a veritable mine of running info. Trawling the globe for current running news on a daily basis, the website enables you to follow specific athletes and events, while the affiliated forum is famed for its advice and analysis.

Tablet takedown

We get hands-on with three of the top tablets on the market to see which one delivers the best results

1 Nexus 7 (second gen)

Price: £199.99/$229
Get it from: www.google.com/nexus/7

Okay, let's be upfront about this one. The second-gen Nexus 7 is an excellent tablet and it's easy to see why many are insisting it's currently the best in the world. It's slick, powerful and without doubt definitive proof that the 17.8-centimetre (seven-inch) form factor works, offering a lightweight slate upon which media, games and online services all shine.

This is largely due to its impressive technical specifications. Packing a Snapdragon S4 Pro Krait 300 1.51-gigahertz CPU, Adreno 320 400-megahertz GPU, two gigabytes of DDR3L RAM and an IPS LCD capacitive touchscreen with a resolution of 1,920 x 1,200 pixels (323 pixels per inch), the Nexus takes almost every other tablet to the cleaners in terms of performance. Indeed, the only other tab that comes close is its bigger brother, the Nexus 10.

This technical prowess translates into excellent usability, with the Android 4.3 Jelly Bean operating system running incredibly smooth and apps launching all but instantaneously. Its low weight of just 290 grams (10.2 ounces), along with its even thinner profile compared to last year's model – 8.7 millimetres (0.3 inches) thick, make holding it with one hand a breeze. This really is the king of today's tablets.

Verdict: ●●●●●

2 iPad mini

Price: £269/$329
Get it from: store.apple.com

We're huge fans of the 17.8-centimetre (seven-inch)-sized tablet and so we are quite happy declaring the 20-centimetre (7.9-inch) iPad mini the best that Apple has ever made. It is thin, super-sleek and simple to use, with Apple's walled garden of an ecosystem familiar and well-structured as ever. However, in light of some recent releases from Apple's main rival, Google, the iPad mini doesn't come out of this head-to-head as unscathed as you might expect.

Technically the mini loses out to the similar Nexus 7 on every front, with its one-gigahertz, dual-core A9 CPU, PowerVR GPU, 512-megabyte RAM and 1,024 x 768 pixel screen all trumped. In fact, the screen may be the most disappointing aspect of the iPad mini, with the modest 163-pixel-per-inch fidelity almost doubled by the Nexus 7. At least the battery life is good, with a solid ten hours on offer.

As ever though, in terms of operating system and applications, this pint-sized iPad punches hard. The curated experiences of the App Store and iTunes remain superb, while iOS 6 – currently updated to 6.1.3 – makes navigating apps, emails, menus and much more both intuitive and enjoyable. This user experience is somewhat checked by the price though, with the Wi-Fi-only, 16-gigabyte model costing £70 ($100) more than Google's Nexus 7.

Verdict: ●●●○○

Highest-res screen
The Nexus 10 comes with the highest-resolution display currently available on a tablet: a 2,560 x 1,600px Super PLS panel. The fact that the monstrous resolution is crammed into just 25.4 centimetres (ten inches) of screen means that everything appears incredibly sharp.

Densest ppi
Despite the fact its big brother, the Nexus 10, takes the crown for the highest overall resolution screen, the Nexus 7's panel technically has the highest ppi density, cramming in a mighty 323. The human eye can't really differentiate over 300 pixels per inch, so this is basically the clearest display ever made.

Apps aplenty
The App Store is by far the iPad's best selling point, with more than 375,000 applications screened and tested by the company. Compared with Google Play, which despite improvement of late is still a bit hit and miss, Apple's app repository is a curated haven.

3 Nexus 10

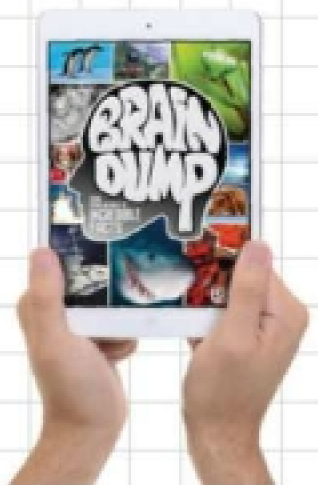
Price: £319/$399
Get it from: www.google.com/nexus/10

The bigger brother to both the first- and second-generation Nexus 7s, the Nexus 10 is a powerhouse of a tablet. Armed with a monstrous 2,560 x 1,600 pixel screen – that sort of resolution is typically the reserve of 76-centimetre (30-inch) computer monitors, a 1.7-gigahertz, dual-core A15 CPU, two gigabytes of DDR3 RAM and a lithium polymer 9,000mAh battery, the 25.4-centimetre (ten-inch) Nexus is the most powerful Android tablet on the market.

With the 10's larger proportions, compared with the mini and the Nexus 7, there comes an additional tier of direct competitors – most obvious being the iPad 4. However, aside from overall build quality – which the iPad 4 wins due to its high level of metal and glass as opposed to the Nexus's polycarbonate – it is much the same story as with the Nexus 7 and the iPad mini. The 10's tech destroys that of the iPad 4 – and does so a good deal cheaper – but Apple's slick OS and app functionality pip that of the Android offering.

Whether or not the Nexus 10 or Nexus 7 is the better device depends on what type of user you are. The size and power of the 10 is immense and if you consume large quantities of high-definition media then the 1080p screen and long battery life make it ideal. However, if you're a more casual all-round tablet user who needs it for web browsing on the go etc then the lighter Nexus 7 series makes more sense.

Verdict: ●●●●○



ON THE HORIZON

We highlight four other items to look out for in the near future

Sony Bravia X9

The first remotely affordable 4K TV – and affordable is used loosely as it's still £4,000 – the Bravia X9 promises HDTV-busting resolutions. Whether or not the 3,840 x 2,160px screen is enough to justify the sort of outlay that could buy a decent secondhand car remains to be seen.

New iPhone

As we enter the autumn months a familiar fruit begins to loom ahead. It is, of course, iPhone manufacturer Apple, which has a tendency to unveil the latest iteration of its all-conquering iPhone in the latter part of the year, with the follow-up to the iPhone 5 now keenly anticipated. Whether or not that device is an update or an entirely new breed of smartphone will only become apparent in the coming months.

NVIDIA SHIELD

Finally released, we have been itching to get the NVIDIA SHIELD handheld gaming console for ages. The system, which looks like an Xbox One controller with a 12.7-centimetre (five-inch) screen attached, is packed with some serious hardware – eg Tegra 4 processor – and can access a wide variety of PC and Android videogames. We have a bit longer to wait until one arrives at **HIW** HQ though.

RetroN 5

Another eagerly anticipated piece of gaming tech is the RetroN 5, a crazy console that has been designed to accept NES, SNES, Sega Genesis, Famicom and Game Boy Advance cartridges. The system, which will enable you to replace five retro consoles with just one sleek box, also delivers improved video and audio thanks to its HDMI support. No release dates have yet been confirmed.

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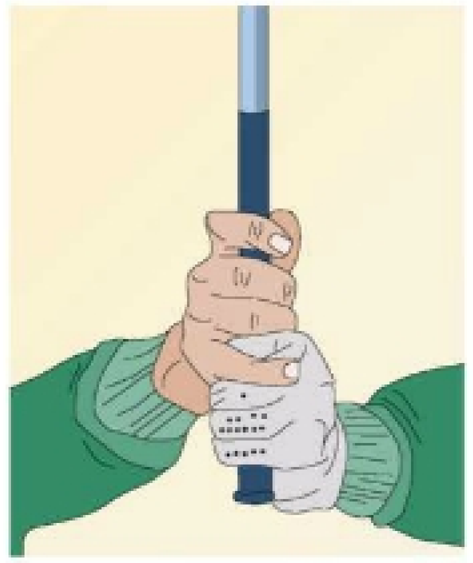
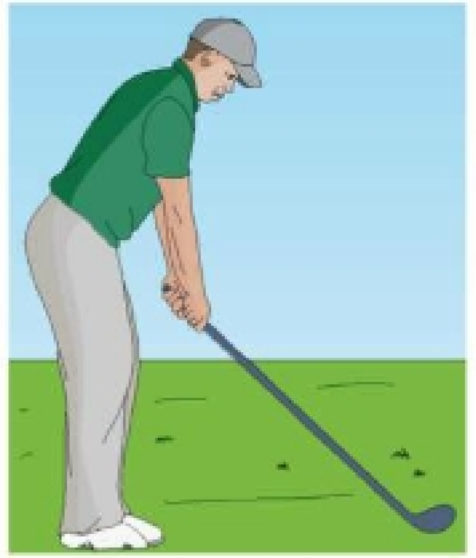
Hit a hole-in-one

With this quick guide to golf, you'll soon get into the swing of taking a shot...

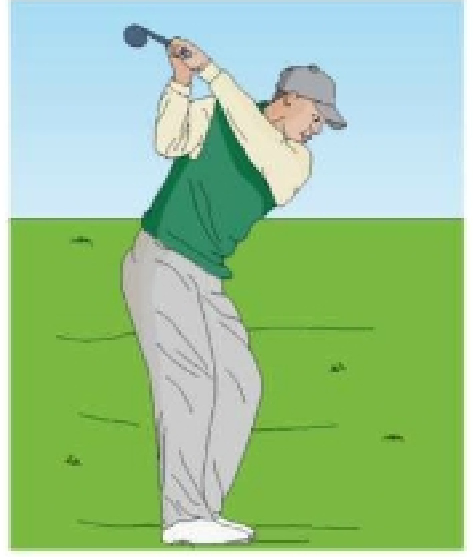
1 Read the environment
Before picking up a club you need to gauge the shot. Wind, for example, can have a major bearing on where you should aim and your intended target's elevation will dictate which club you use. For instance, if the green is uphill from your position then you'll need to select a stronger distanced club (say, a four-iron rather than a six-iron). Equally if the wind is blowing left to right, you will have to aim farther left to compensate.



2 Get a grip
You won't hit anything with much success unless you know how to hold a golf club. There are different grips, eg overlapping, interlocking and baseball types. For the most common grip (overlapping) take hold of the shaft with your left hand, place the little finger of your right hand between the middle and forefingers of the left, and then close both around the club ensuring that your thumbs are aligned downwards.



3 The right stance
Start by placing your feet shoulder width apart and parallel to the target's line (the direction to the green). While the back foot should remain 90 degrees to the target, the front foot should be flared out towards it by about 20 degrees; this will help to rotate your body during the foreswing. For ball positioning, the stronger the club you are using, the farther forward the ball needs to sit in the gap between your feet.



4 Backswing
Before hacking at the ball, take some time to position the club at the top of your swing. To do this, draw your club back slowly, brushing the face along the grass for as long as possible. Once the club leaves the ground maintain a smooth arc until the club is positioned above your head and pointing forwards along the target path. Do not overextend as this will likely lead you to cut across the ball's face and mishit it.

5 Foreswing
Keeping your eyes firmly on the ball, bring the club down in a smooth arc, shifting your body towards the target and allowing your right shoulder to bring your right elbow through at hip height. Try to ensure that as much rotation as possible occurs in the hips and not in the upper body, as this will make hitting the ball in a straight line easier. After contact, continue to bring the club through on its arc and allow your body to naturally rotate into a balanced finishing posture.

Disclaimer: Neither Imagine Publishing nor its employees can accept liability for any adverse effects experienced when carrying out these projects. Always take care when handling potentially hazardous equipment or when working with electronics and follow the manufacturer's instructions.

In summary...
Key to hitting a hole-in-one – or any half-decent golf shot – is remaining in control at all times. By breaking any shot down into a series of stages, this can be achieved with greater consistency. In general, by positioning yourself correctly, swinging the club slowly and keeping your eyes on the ball until after it is struck, anyone can become a golf pro in no time.

NEXT ISSUE
- Make pancakes
- Scuba dive

Plaster a hole in your wall

Learn how to fill in the gaps in your walls with a three-step plastering walkthrough

1 Prepare the wall
First things first, you must prepare the crack or hole; fail to do this and it's likely that the plaster will not bond securely with the wall. Remove any loose debris in or around the area that needs attention and then sand down any sharp edges. The first job is best tackled with a paintbrush, as this enables you to brush away debris easily, even if it is deep in the wall. The second task, meanwhile, calls for a small piece of sandpaper.

2 Fill the gap
Once the crack or hole is smooth and clear, it's time to fill the recess with fresh plaster filler. This is best done by generously applying the filler along the line of the crack/hole, ensuring that the material fills the cavity as deep as possible. Don't worry about the filler looking particularly neat at this stage. To remove any excess, take a trowel and, keeping it perpendicular to the wall, scrape away in one smooth action.

3 Smooth things over
The hole/crack should now be filled but the finish may look uneven or dipped – this is normal so don't panic! Using your trowel remove any bumps in the plaster and apply a second layer, using your trowel to smoothly smear the filler over the area before once more removing any excess. Finally, check the second layer for any imperfections and, if flush with the surrounding wall, leave to dry before painting/wallpapering.

In summary...
Before plastering ensure the area is properly prepared to help get a smooth surface that won't crumble off. You can make your life much easier by using the right tools – such as paintbrushes, sandpaper and a trowel. Be patient too – expect there to be at least two applications.

QUICK QUIZ

Test your well-fed mind with ten questions based on this month's content and win a model of a Type 45 destroyer from Airfix!

Answer the questions below and then enter online at **www.howitworksdaily.com**

1 How many pixels per inch does the screen on the second-gen Nexus 7 have?

2 How many missions did the Space Shuttles complete before they were retired?

3 Roughly how long was a fully grown Ankylosaurus dinosaur in metres?

4 On what date was the *Mona Lisa* painting stolen from the Louvre in Paris?

5 What is the displacement of the British Type 45-class destroyer in tons?

6 How much will the ESA's JUICE mission to Jupiter cost in US dollars?

7 How many times weaker is the gravity on Triton compared with Earth?

8 What size battery does the Xperia Z Ultra waterproof smartphone have?

9 How many quills does the North American porcupine have on average?

10 The Spanish Steps in Rome comprise how many steps?

ISSUE 50 ANSWERS
1. 250mn years **2.** New Zealand **3.** 98% **4.** 1893 **5.** 40
6. John Roebling **7.** 80km **8.** 1858 **9.** 6,400km **10.** 1959

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WIN!

We enjoy reading your letters every month, so keep us entertained by sending in your questions and views on what you like or don't like about the mag. You may even bag an awesome prize for your efforts!

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WIN YOUR VERY OWN STARTER TELESCOPE!

The writer of next issue's 'star' letter will win themselves a Visionary FirstView Starter Telescope. Visit www.howitworksdaily.com for details.

HMS Ambush, an Astute-class submarine, is currently taking part in sea trials

Letter of the Month

A Noble cause

Dear HIW,

Huge respect for Richard Noble and the work he does in pushing the boundaries of engineering. However, in issue 50 of **How It Works** Richard was interviewed as saying 'the British haven't really done anything astonishing in engineering terms since Concorde', but this is not true. Here in Barrow-in-Furness at the shipyard owned and operated by BAE Systems we have designed and are building the most complicated machines in the world: Astute-class submarines. In fact, it has been stated by our US cousins that this engineering feat has resulted in machines more complicated than NASA's Space Shuttle. Surely there cannot be a better example of the huge engineering skill existing in this country than these magnificent vessels.

Russ Rushton

There's no denying a great many significant feats of engineering excellence were born from the minds and hands of Britons – and we've no doubt Richard Noble appreciates this too. Many of the letters we receive each month are from youngsters keen to share their fascination and thoughts on the subject of engineering so long may people like Noble inspire new generations. We enjoy hearing of the UK's pride in its achievements and so we'd like to award you Letter of the Month.

No such thing as coincidence?

I just received issue 49 of your magazine in the mail and I am amazed. At school we are studying megacities… And lo and behold, you have an article about megacities in your magazine. In science we are looking at mould. You have an article about mould in your magazine. In the holidays we visited Surfers Paradise [in Queensland, Australia]. You had an article in the How To… section about surfing. In the holidays we also went to Dreamworld [theme park in Queensland]. There was a ride that my dad said used centrifugal force. I didn't understand it when he tried to explain, but thanks to the Brain Dump, I now know what centrifugal force is. Keep up the great work!

Maggie

You honestly wouldn't believe the number of letters we get like this, Maggie. It's genuinely bizarre how often such coincidences happen. Maybe we're just tuned in to what our readers want to know…

Three cheers for musketeers!

My entire family enjoys reading your magazine and it has been a particular pleasure to watch my son – now 11 – dive for it as it lands on the mat each month. In this month's edition [49] there's a piece on musketeers. In the 'Sword' annotation on the diagram, it says that musketeers 'were trained to fight both on horseback like dragoons and on foot like infantry'. Felix would like to point out that dragoons rode to battle and then fought as infantrymen. Meanwhile, right or wrong (Wikipedia suggests the term's meaning changed over time), I would simply like to thank **How It Works** for engaging his interest to such a degree.

Jamie Hussey

Thanks for your letter, Jamie (and Felix) – and you are both absolutely right. Initially, dragoons would ride into battle and dismount before they started fighting. However, they did eventually adopt cavalry tactics and were able to fight from horseback as well, so the definition of dragoon did evolve over the years. We're glad that your family enjoys the magazine, and we are all super-impressed by Felix's keen eye for detail!

Diabetes to get the HIW treatment

Can I start by saying that I am a subscriber and I absolutely wait *without patience* for the next copy of **How It Works** to land through my letterbox.

I was wondering if you could do a small feature for me? I am a diabetic and every day I have to test my blood on numerous occasions. You prick your finger with the lance then put the drop of blood onto the test strip. You then insert the test strip into a small blood meter that gives an almost-instant readout revealing your blood glucose levels.

How do these strips work? How does the blood reader analyse the small sample of blood so quickly? Thank you for the great learning tool that your magazine has become for me. It certainly keeps the old grey matter working.

Joe

We've had a few queries about this. You'll read it here next issue, Joe.

© Thomas McDonald; Thinkstock

> "I can occasionally surprise my five grandchildren with little bits of technical knowledge"

Eagle-eyed reader

I am 66 years old now – last week, in fact – and I have to say I've always loved expanded drawings of objects, cars, ships and planes, since I took the *Eagle* comic in the early-Sixties. However, thanks to your magazine I can occasionally surprise one or all of my five grandchildren with little bits of technical knowledge I manage to glean from your pages. In fact, Tomos and Adam are both 14 and have started to exhibit some of the arrogance of youth so I can sometimes throw them a question they can't bluff their way through. Keep up the good work.

PT Proud

Thanks for your email. Publications like the *Eagle* inspired us so it's great to hear that reading this is evocative of those rich books. It always makes us proud to hear about the various benefits our readers get from reading and sharing the information we provide, so thanks.

A handy article

I receive your magazine monthly and read it cover to cover. I really enjoy it and it is so informative. This past Mother's Day I had a horrible accident to my left hand with a long surgery to repair it. Unfortunately I now have numbness to two of my fingers and the side of the hand which hopefully will be normal again within a year. My question is, was an issue of **How It Works** ever published with an article looking at the hands? If so I would like to obtain a copy.

Charlene Palmer

We're sorry to hear about your hand, Charlene, and hope you're recovering well. We did a two-page feature on the anatomy of the hand back in issue 14, which unfortunately is out of stock at our eShop. However you can still download the digital edition to a smartphone or tablet – just head to www.greatdigitalmags.com.

To learn more about diabetic glucose test kits, be sure to check out the next issue!

What's happening on... Twitter?

We love to hear from **How It Works'** dedicated followers. Here we pick a few tweets that caught our eye this month...

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@HowItWorksmag If the issues get better every month then the next issue must be incredible! Because issue 50 was AMAZING!

Charisma @charis_webster
@HowItWorksmag just seen latest issue BOSH that's a cover! I like it :)

Damian Butt @ImagineMD
@HowItWorksmag. Essential reading for the train – awesome '50 Greatest Inventions' feature

Tom R @blockswitch
WOOOOO! Just got the new **@HowItWorksmag** 50 GREATEST INVENTIONS

Sarah Hamilton @sarahisobelh
Reading the latest copy of **@HowItWorksmag** I've got an assignment on the musketeers so it's perfect timing!

Steve Bowbrick @bowbrick
I like it when they have the 'Learn About' box on the front cover of **@HowItWorksmag**

Wadih Merhy @wadihmerhy
@HowItWorksmag My personal favourite! I never skip an issue

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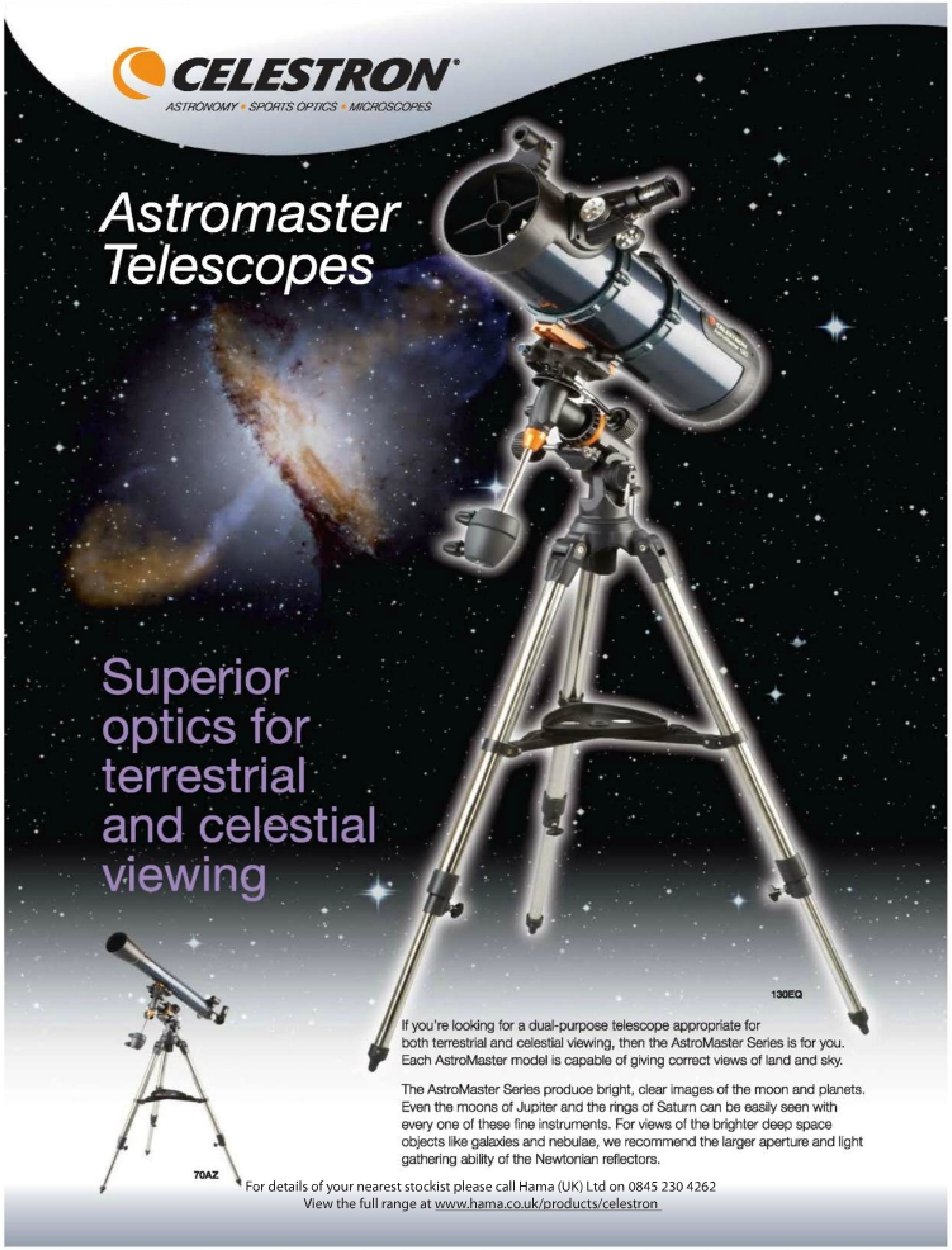
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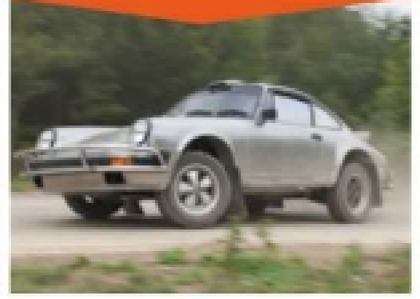

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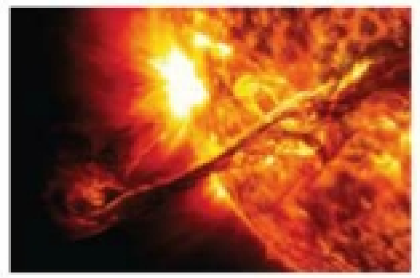

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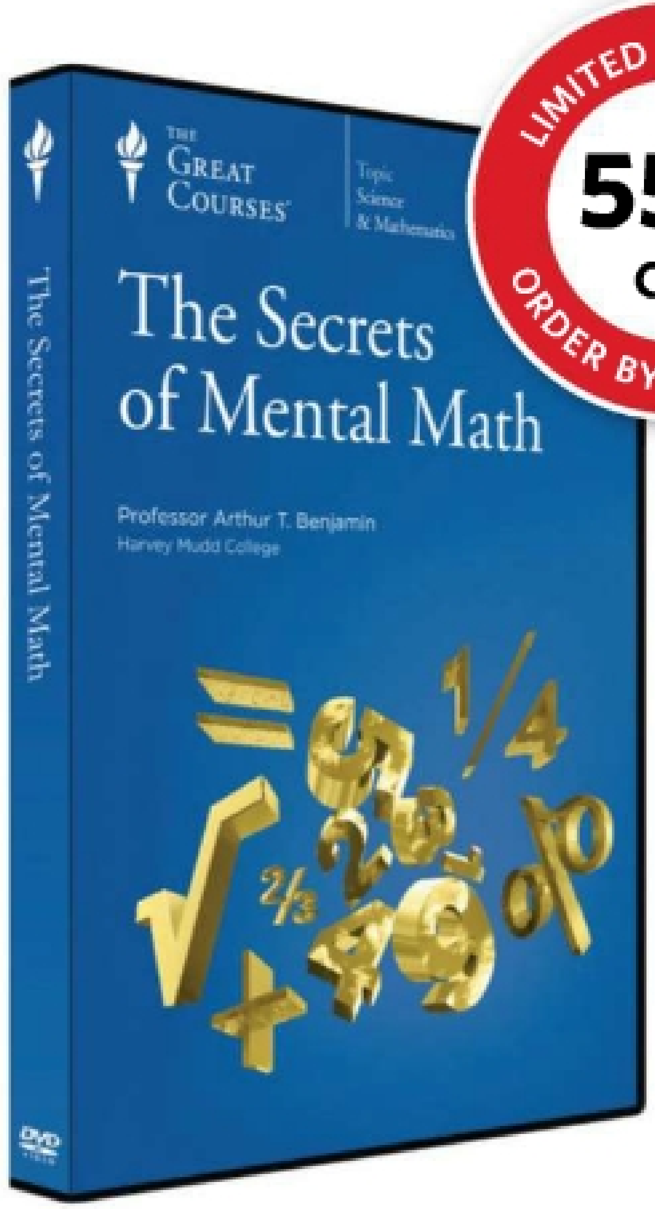

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